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Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

National Shoreline Erosion Control Development and Demonstration Program

Monitoring of Beachsaver Reef with Filter Blanket and Double-T Sill at Cape May Point, New Jersey, Section 227 Demonstration Site

First Year Monitoring — 2002-2003

Donald K. Stauble, Randall A. Wise, and J. Bailey Smith

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ABSTRACT: The first National Shoreline Erosion Control Development and Demonstration project is located at Cape May Point, NJ, the southernmost beach along the New Jersey coast. This site was selected to evaluate the functional, structural, and economic performance of the patented Beachsaver Reef prefabricated concrete submerged breakwater and the less expensive prefabricated concrete structure called a Double-T sill. This demonstration project was developed through a cooperative effort of the U.S. Army Corps of Engineers Headquarters, Coastal Engineering Research Board, Coastal and Hydraulics Laboratory, Philadelphia District, the state of New Jersey and Cape May Point. Cape May Point has a history of beach erosion due to the combined influence of waves and tidal currents due to its location at the north side of the entrance to Delaware Bay. The Beachsaver Reef was installed between August and September 2002 at the seaward end of groin cell 5. The Double-T sill was installed in September 2002 at the seaward end of groin cell 6. Groin cell 4 acted as a control cell without any structures, but a small beach fill was placed twice during the monitoring period. Monitoring includes dune, beach and nearshore beach profile surveys, structure surveys to measure settlement and scour, waves and current measurements, sediment sampling and aerial photography analysis of shoreline change. After one year, evaluation of profiles and shoreline change indicates the functional performance of the Beachsaver Reef has stabilized the shoreline and retained sand within the cell, while the Double-T sill has not. The structural performance indicates that the Beachsaver Reef has experienced settling in the western part of the cell while the Double-T has settled below the surface within the first 6 months. The economic analysis will be evaluated after the third year of monitoring.

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Preface

This study is being conducted by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Coastal Engineering Branch, and the U.S. Army Engineer District, Philadelphia, Coastal Planning and Coastal Engineering Branches. Funding was provided by the National Shoreline Erosion Control Development and Demonstration Program (Section 227). The program was authorized by the Water Resources and Development Act of 1996 (Public Law 104-303, 110 Statute 3658), dated 12 October 1996. Mr. William R. Curtis, CHL, is the Section 227 Program Manager. Dr. Donald Stauble, CHL, is the Cape May Point, New Jersey, Principal Investigator. Mr. J. B. Smith, Philadelphia District, is the Project Manager.

Work was performed under the general supervision of Dr. Yen-Hsi Chu, Chief, Coastal Engineering Branch, CHL; Ms. Joan Pope, former Technical Director for Flood and Coastal Storm Damage Reduction, CHL; Mr. Thomas W. Richardson, Director CHL; and Dr. William D. Martin, Deputy Director, CHL. This report was prepared by Dr. Stauble, Coastal Engineering Branch, CHL; Mr. Randall A. Wise, Coastal Engineering Branch, Philadelphia District; and Mr. J. B. Smith, Coastal Planning Branch, Philadelphia District.

Messrs. Tim Rooney, Dwight Pakan, and Jeff Gebert of the Philadelphia District provided assistance in data collection, analysis, and project management. Mr. Michael Giovannozzi, URS Corporation (formerly with the Philadelphia District), was the Project Manager for construction and initial monitoring. Mr. George Turk, URS Corporation (formerly with CHL), was the initial Principal Investigator during project design phase. Messrs. Bernie Moore (ret.), Gene Keller, and John Garafolo of the New Jersey Department of Environmental Protection (NJDEP) provided assistance in project planning, implementation, and monitoring. The NJDEP is the non-Federal sponsor of the project. Mayor Malcolm Fraser, of the Borough of Cape May Point, New Jersey, is supporting the local interests in the project. Survey data and sediment samples were collected by the Richard Stockton College of New Jersey, Coastal Research Center, under the direction of Dr. Stewart C. Farrell, with Messrs. Steven Hafner, Christopher Constantino, and Crist Robine, and student assistants. The CHL Measurement and Analysis Group's Messrs. Sam Varnell, Mike Kirklin, and Christopher Callegan collected wave and current data. Dr. Joon Rhee, CHL, assisted with wave and current data analysis. Messrs. Thad Pratt and Terry Waller, CHL, provided logistics, GPS navigation assistance and ADCP data analysis. Preinstallation surveys were collected by Gehagan and Bryant and Vandemark and Lynch. Dr. Tom Harrington and students, Stevens Institute of

Technology, collected some immediate preinstallation survey data and sediment samples. Dr. Richard Weggel, Department of Civil, Architectural and Environmental Engineering, Drexel Institute of Technology, and Drs. Stewart C. Farrell and Mark Mihalasky, the Richard Stockton College of New Jersey, provided helpful comments and review of the report.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC and COL James R. Rowan, EN, was Commander and Executive Director.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
inches	2.54	centimeters

1 Introduction

The U.S. Army Engineer Research and Development Center (ERDC) was authorized under Section 227 of the Water Resources and Development Act of 1996, called the National Shoreline Erosion Control Development and Demonstration Program, to conduct research and to demonstrate prototype-scale innovative or nontraditional methods of shoreline erosion control and evaluate the effectiveness of these devices or methods. This research and development effort has three primary objectives: (a) to assess and advance the state of the art of beach erosion control technology, (b) to encourage and achieve the development of innovative solutions to beach erosion control, and (c) to communicate the findings to the public and develop means to further the use of well-engineered alternative approaches to beach erosion control (Curtis and Ward 2004). Under this Research and Development initiative, several projects are underway on all four coasts of the United States. Cape May Point, NJ, was selected as the first demonstration site with the purpose of evaluating the functional, structural and economic performance of the patented Beachsaver Reef™ prefabricated concrete submerged breakwater and a less expensive, prefabricated concrete structure called a Double-T sill.

Data analyzed in this report include profile surveys, settlement surveys, sediment samples, wave and current measurements, and aerial photography. Profile and shoreline change data were evaluated to assess the project's functional performance in retaining sand within the groin compartments and maintaining a stable shoreline position in an area subject to beach and dune face erosion and landward retreat of the shoreline. Scour, settlement, and reorientation were documented to evaluate the project's structural stability.

Background

Cape May Point, NJ, is the southernmost beach along the New Jersey shore. ERDC's Coastal and Hydraulics Laboratory (CHL) and the U.S. Army Engineer District, Philadelphia, planned, designed, and constructed this demonstration project to assess the use of prefabricated concrete structures for erosion control. The proposed plan for the demonstration project was developed through coordination with Headquarters, U.S. Army Corps of Engineers (HQUSACE), the Coastal Engineering Research Board (CERB), the State of New Jersey Department of Environmental Protection (NJDEP), and local interests at Cape May Point. The NJDEP is the non-Federal sponsor for the demonstration project.

The southern New Jersey coast, south of Little Egg Inlet, comprises several short barrier islands separated by numerous inlets. These barrier islands are oriented generally in a northeast-southwest direction. The last inlet in this chain is Cape May Inlet (also called Cold Springs Inlet) which separates Five Mile Beach (a drumstick barrier island containing, from north to south, the cities of North Wildwood, Wildwood, and the Borough of Wildwood Crest) from a mainland cape feature (comprising the city of Cape May, Cape May Meadows, and the Borough of Cape May Point). Cape May Meadows contains Cape May State Park on the western end and the Cape May Migratory Bird Refuge (nature conservancy) on the east. The shoreline from Cape May Inlet to Cape May Point is oriented in a more east-west direction.

Site Characteristics

The beach at Cape May Point covers a 1.8-km (1.1-mile[1]) length of shore along the north side of the entrance to Delaware Bay at the southern tip of New Jersey (Figure 1). The beaches have characteristics of both an open Atlantic Ocean beach and an estuary beach setting. The beachfront at Cape May Point has experienced erosion that is threatening the 4.5-m (15-ft) high (NAVD 88) primary dune and upland structures located behind the dunes. Waves break on the beach from the east to south from waves originating in the Atlantic Ocean, and from the south to west from waves originating across the 26-km (16-mile) fetch of the mouth of Delaware Bay. Wave heights average 0.6 m (1.9 ft) in the summer and 1.2 m (3.9 ft) in the winter, with higher waves common during storms. The mean semidiurnal tide range is 1.48 m (4.85 ft). In addition to wave activity, a north marginal flood channel parallels the shore 183 m (600 ft) offshore of the beachfront. Flood-tidal currents in this channel, at maximum, are estimated to be on the order of 0.77 m/sec (2.5 ft/sec). The net sediment transport is approximately 153,000 cu m/year (200,000 cu yd/year) to the west into the bay and is a function of angle of wave approach as well as predominantly bayward tidal flow along this marginal flood channel just off the beach (USAED, Philadelphia, 1997). The ebb flow out of Delaware Bay is mainly confined to an ebb channel located further offshore, but some ebb flow is also seaward along the north marginal flood channel.

Beach and dune erosion has been a problem at Cape May Point for some time due to this interaction between waves and tidal currents. Over a period from 1879 to 1943, the shoreline generally eroded (Figure 2). After construction of jetties at Cape May Inlet in 1911, the city of Cape May built 24 groins between 1924 and 1929 to slow an erosional trend progressing along the coast from east to west. In 1930, a steel sheet-pile bulkhead was placed between the existing timber cribs along the beachfront of Cape May City. Between 1930 and 1942, the Borough of Cape May Point, further to the west, also constructed a series of steel groins along the borough's shoreline to slow erosion. Erosion rates were measured around 6.1 m/year (20 ft/year) just west of Cape May Inlet and between 5.2 to 6.1 m/year (17 to 20 ft/year) in the vicinity of Cape May Meadows from 1927 to

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[1] Units of measurement in the text of this report are shown in SI units, followed by non-SI units in parenthesis. In addition, a table of factors for converting non-SI units of measurement used in tables in this report to SI units is presented on page vii.

1943 (U.S. Congress 1953). A timber/steel bulkhead was constructed at the eastern end of Cape May Point in 1934 to protect upland property. Erosion continued downdrift of Cape May Inlet between 1939 and 1941, and eight additional groins were constructed in Cape May City.

At Cape May Point, a series of nine timber and stone groins, each approximately 152 m (500 ft) long, were completed in 1945 to help stabilize the eroding shoreline and to replace earlier steel groins. They were placed about 150 to 300 m (492 to 984 ft) apart creating eight groin cells (Figure 3). Between 1946 and 1952, Cape May City replaced the smaller groin field from east to west with five large stone groins and a continuous stone seawall. Two new groins were constructed on the west end of Cape May City between 1952 and 1954. After the Ash Wednesday Northeaster of 1962, the city of Cape May rehabilitated the existing groins and constructed two additional groins for a total of nine groins that covered the entire length of the city's beachfront. This shore protection stabilized the Cape May City's shoreline, but west of the last groin at Third Avenue, a crenulated-shaped shoreline formed in front of the unprotected Cape May Meadows. By the mid-1980s, little sand was on the city of Cape May beach and a beach-fill project was constructed between 1988 and 1991. Additional fill was placed in 1993, 1995, and 1997, but stopped at the Third Avenue groin, leaving the Cape May Meadows shoreline some 396 m (1,299 ft) landward of the Cape May City seawall (USAED, Philadelphia, 1997).

To the west of Cape May Meadows, the stone groins at Cape May Point have been moderately successful. From 1971 to 1994, the pocket beaches within the groin cells experienced variable erosion and dune scarping. Cells 1 to 5 (closest to the ocean) experienced alternating erosion and accretion and cells 6 to 8 (closest to the bay) were generally accretional. The general trend since 1994 has been erosion in all cells. This erosion now threatens upland infrastructure. A stone revetment in cell 1 at the dune base has protected the dune and a large shorefront building, but there is no dry beach in that cell. Erosion east of the first groin required placement of stone-filled polymer baskets along the dune face to protect the dune in front of the Cape May Lighthouse and park. In May 1994, a 305-m- (1,000-ft-) long Beachsaver Reef was installed in cells 2 and 3 as part of the state of New Jersey Pilot Reef Project. These reefs were placed across the entire length of the cells at the seaward end of the groins, effectively making an enclosed compartment. A 2-year monitoring effort concluded that the Beachsaver Reefs stabilized the inshore beach by reducing sand losses from the beach profile landward of the reef structure (Herrington et al. 1997). Cell 2 retained almost all of its preinstallation sand volume and cell 3 lost a smaller amount of sand compared with cell 4 that acted as a control with no structure. Most of the sand retained within the protected cells appeared to have originated from the eroding dune. Because of limits in the monitoring data, results were inconclusive in demonstrating the effectiveness of the structures in retaining sand within the groin compartments. The reef units settled soon after placement and reduced their wave attenuating abilities. A scour trough formed on the landward side of the reef units, but the structure did act as a perched beach retaining sand in the intertidal area in this closed compartment configuration. Continued dune scarping over time led to the construction of a seawall of rock rubble and gabions in 1999 to 2000 just seaward of the dune base in cell 5 to prevent loss of the dune. A 15,292-cu m (20,000-cu yd) truck haul beach fill was placed in cell 3 behind the

Beachsaver Reef and in control cell 4 in December 2000 to January 2001 to protect the dune from scarping. An additional 7,340-cu m (9,600-cu yd) truck haul beach fill was placed in cell 4 in March 2004 to mitigate for continued erosion.

Project Components

The Section 227 project layout was influenced by the existing shore protection structures, which segmented the shore into eight groin cells. The Section 227 demonstration project was placed in cells 5 and 6 to mitigate for existing erosion. The entire adjacent area was included in the project monitoring because of the large number and location of shore protection devices (various types of seawalls and beach fills) and wave and current interactions over a sand shoal in the nearshore. The groin cells and additional shore protection hard structures and beach fills are indicated in Figure 3, and are numbered “1” through “8” from southeast to northwest. Groin cells 1, 2, and 3 are 152 to 168 m (500 to 550 ft) in length, as measured between the seaward ends of the structures. Cells 4 through 8 are between 213 and 244 m (700 to 800 ft) long. Cell 1 has no dry beach, and cells 2 and 3 have an existing Beachsaver Reef that was placed in 1994 as part of the State of New Jersey Pilot Reef Project. Cell 4 was a control cell for that project and is also a control for the Section 227 project. However, a small beach fill was added to cells 3 and 4 to protect the dune base from erosion in December 2000, before the Section 227 project was constructed. Additional fill was added in cell 4 in March 2004. Cells 7 and 8 also are control cells in that they have no nearshore, submerged breakwaters, or beach fills.

Beachsaver Reef

In the summer of 2002, a Beachsaver Reef was constructed at the seaward end of cell 5, as part of the Section 227 project. The triangular Beachsaver Reef is a narrow-crested prefabricated concrete breakwater structure 3.05-m- (10-ft-) long, 4.57-m- (15-ft-) wide and 1.83-m- (6-ft-) high, weighing 19.1 metric tons (21 tons) (Figure 4). The units have a narrow crest width of 0.42 m (1.4 ft). Seventy-two individual units were locked together by a built-in hook and eye configuration to make a long, submerged, continuous reef structure at the seaward end of the groins. Rock was placed between the end reef units and the groins, enclosing the entire cell as a perched beach. The marketed objective of these structures is wave attenuation. Past experience indicates that they are poor wave attenuators for this setting due to the narrow crest width (Stauble and Tabar 2003). The purpose of the Section 227 project is to evaluate how the structure functions as a sill by retaining sand within the groin compartment.

Monitoring of the 1994 installation showed that the reefs were somewhat effective in trapping sand within the compartments (primarily in the intertidal area of the beach profile). Scour at the landward base of the reef caused it to settle. Wave attenuation was determined to be around 10 percent. While most of the sand was retained in cell 2, cell 3 experienced erosion over the study (Herrington et al. 1997). To prevent the scour and settlement that was measured in the 1994 installation, the new Section 227 construction in cell 5 placed units

on a geotextile scour apron (Figure 5). This approximate 18 sq m (193 sq ft) scour apron has an anchor tube filled with concrete on its landward end to stabilize the entire apron and anchor the mat to the bed. The reef units were placed at a water depth of -2.7 m (-9 ft) with its crest located at mean low water (mlw). This placement is shallower than the original deployments in cells 2 and 3. Figure 6 shows the design elevation of the Beachsaver Reef relative to the bed and mlw. The tidal datum information is from the National Oceanic and Atmospheric Administration/National Ocean Service (NOAA/NOS) tide gage located at the Delaware Bay entrance to Cape May Canal, 4.1 km (2.6 miles) to the north.

Double-T sill

In cell 6, a precast concrete Double-T structure was placed at the seaward end of the groins to act as a sill and create a perched beach (Figure 7). The name for this structure comes from the shape of the units, which have two vertical legs perpendicular to a flat base. When viewed on its end, it looks like two "T's." The Double-T module is relatively low-cost and commonly used to construct parking garages and bridges. In a typical use, it is used for the floor supports of a parking garage or bridge roadway where the units are placed with the legs in a downward position and the flat top is the floor of the parking surface or bridge road surface (Figure 7b).

The units for this particular shore protection application is made of marine grade concrete which has higher strength and better resists seawater weathering. Epoxy-coated rebar was used for reinforcement in the flat deck and legs. The units were cast at the factory and trucked to the staging area. The units are 9.14 m (30 ft) long and 3.66 m (12 ft) wide, with the vertical legs extending 0.8 m (2.6 ft) from the flat base (Figure 7a). A single unit has a weight of 17.3 metric tons (19 tons). To create the sill, 22 units are placed end to end in an inverted position with the flat surface on the sand bed and the legs extending up into the water column (Figure 7c). The sill was placed at -2.7-m (-9-ft) depth mlw, which puts the top of the legs at an elevation around -1.9 m (-3 ft) mlw. Unique to this application, the legs on one end of each unit were extended to interlock adjacent units (Figure 7d). These leg extensions were designed to lock the units together to maintain a linear orientation of the sill. The sill was located near the seaward end of the groins and was connected to the groins at both ends by rock. The Double-T crest was approximately 1 m deeper in the water column than the Beachsaver Reef, allowing more water to circulate into and out of the groin compartment (Figure 6).

Control cell

Conditions at Cape May Point present challenges to identify a true control beach site where natural processes outside the influence of any coastal engineering structures can be measured. The recent shore protection modifications in the eight groin cells are presented here to show the site's complex nature.

Cell 4 had the least amount of modifications to the beach area and is the control cell for assessing changes in sand volume, shoreline position and

response to beach fills in the absence of hard shore protection structures. This groin compartment has no nearshore submerged breakwater structures, but was part of the small beach fill that placed 8,614 cu m (11,266 cu yd) of upland sand fill on the berm area in January 2001 and 7,358 cu m (9,623 cu yd) in March 2004. Cells 7 and 8 further to the west and into the bay are also control sites in that they do not have any structures within the cells. The change in shoreline orientation from cells 1 to 8 ranges from almost pure ocean beach processes to the east in cells 1 to 3, to bay beach processes in cells 7 to 8. Cells 4 to 6 are transition cells between the ocean and bay processes. All eight compartments are being monitored.

Previous reef structures, revetments, and beach fills

Cell 1 has no dry beach and is backed by a large rock revetment. Cells 2 and 3 have a pervious installation of the Beachsaver Reef. Cell 2 also has a rock seawall on the eastern third of the dune base and a rock filled gabion revetment along the rest of the base of the dune. Cell 3 also had a small 6,678-cu m (8,734-cu yd) beach fill in January 2001. Cells 2 and 3 are the sites of the second of three installations of the Beachsaver Reef as part of the State of New Jersey Pilot Reef Project in May of 1994. (The other two sites were at Avalon and Belmar/Spring Lake). Fifty beachsaver units were placed in each cell, which covered 137 m (450 ft) each at the seaward end of the two groin compartments between Lehigh and Whilldin (cell 2) and Whilldin and Coral Avenues (cell 3). The goal of this installation was to minimize offshore sand losses from these groin compartments (Herrington et al. 1997). The reef was placed in water depths of between -2.1 and -2.4 m (-7 and -8 ft) mlw, with a structure crest between 0.15 and -0.61 m (0.5 and -2.0 ft) mlw (Bruno et al. 1996). This installation was lower than the Section 227 placement in cell 4. Based on experience with settlement at the first installation of the Beachsaver Reef at Avalon, NJ, in 1993, a geotextile fabric was placed on the seabed under the units. Scour along the landward and seaward face of the reef structure in Avalon also prompted the placement of a 1.3-m- (4.5-ft-) wide polyethylene geomattress filled with stone on both the landward and seaward sides of the Cape May Point installation. Steel H-piles were also driven into the bed at the ends and in transition units in the middle of the structure, where the orientation of the reef changed to further stabilize the structure. Rock was also added at the ends of the reef to tie it into the groin ends. These two Beachsaver Reefs are still in place. A summary of that installation's 2-year monitoring of performance is presented in Stauble and Tabar (2003). Cell 4 was used as a control in that project. During the 2-year postinstallation monitoring, cell 2 retained most of the sand in that compartment. Cell 3 lost some sand over the 2-year period. Cell 4, acting as the control, lost the most volume of sand during the monitoring period (1994-1996).

With continued erosion of the beach at Cape May Point, and scarping of the dune face, a small emergency beach fill was placed in cells 3 and 4 in January 2001 as a part of the Section 227 project. This sand fill was included as a feature of the 227 project specifically to determine effectiveness of the existing structure in cell 3 in retaining sand in comparison to the unstructured cell 4. Sand obtained from an upland sand quarry source, was trucked to the site and placed in cell 3 on the beach from the base of the dune to the foreshore and was dressed by

bulldozer. This placement was on the landward side of the 1994 Beachsaver Reef. Sand was also placed in cell 4 from the base of the dune out into the foreshore. Monitoring of that fill included annual beach profiles since July 2000. Due to erosion of the toe of the dune during the winter of 2003/2004, another fill was placed in cell 4 as part of the Section 227 project. The March 2004 beach fill placed a total of 7,358 cu m (9,623 cu yd) in cell 4; 2,918 cu m (3,817 cu yd) of sand was obtained from the Cape May Canal Dredge Disposal Area; and 4,439 cu m (5,806 cu yd) of sand was obtained from an upland commercial sand quarry source. Sand was trucked to the site and dressed by bulldozer. Cell 5 contains a combination stone and gabion revetment at the base of the dune that was installed in 2001 before the Section 227 project began to protect the dune toe from erosion. Cells 5 and 6 were chosen as the Section 227 test sites, since these cells have experienced beach and dune erosion in the past.

Objectives

Cape May Point's shoreline is somewhat unique with strong flood- and ebb-tidal currents just seaward of the existing groins that play an important role in the movement of sand along this beach. Waves approach the beach over a range of 180 deg from east to west and have an influence on sand transport. Larger waves approach from the east to south quadrant from the Atlantic Ocean. The combination of the waves and tides produce a longshore current just seaward of the groin tips that has resulted in erosion in the groin compartments. Aerial photographs from various dates show accretion of sand on either side of the groins at various times, which may indicate that the longshore currents alternate between flood and ebb dominance over time as a function of varying wave approach angles and current interactions. Predominant transport in the flood direction results from prolonged waves from the east and southeast. Predominant transport in the ebb direction occurs with prolonged waves from the south and southwest. Limited current and directional wave data restrict the understanding of the active sediment transport processes at Cape May Point.

Primary objectives of the demonstration project include the following:

a. Evaluate the effectiveness of the submerged structures in retaining sand on the beach as compared with unprotected groin compartments.

b. Evaluate the stability of the Beachsaver Reef and the Double-T submerged sill.

c. Determine (as a long-term objective) if these structures extend the time between periodic renourishments for the proposed Cape May Meadows to Cape May Point beach-fill project scheduled for construction at the end of FY 04 (Giovannozzi et al. 2004).

Initial monitoring of the project over the first year has focused on comparing retention of native sand behind the Beachsaver Reef in cell 5 with that behind the Double-T sill in cell 6. Monitoring will also examine the behavior of the remaining advanced fill placed in cells 3 and 4 in January 2001 to evaluate the effectiveness of the older Beachsaver Reef in cell 3 in reducing loss of sand from

the beach relative to the control open groin compartment in cell 4. The other cells (1, 2, 7, and 8) will also be monitored to evaluate relative beach change in the absence of sand fill for the various structure and control configurations.

The Lower Cape May Meadows - Cape May Point Federal Beach Nourishment/Environmental Restoration Project is scheduled for construction (subject to Congressional funding) following the first year of Section 227 project monitoring. The Federal project includes placement of a beach fill in cells 1 through 6 of the Section 227 Cape May Point Demonstration Project area. Sand will be pumped onto the beaches from an offshore borrow area. The fill template will be inside the groin tips and submerged breakwaters. Fill material will be placed in the existing scour trench seaward of the groins off of cells 1 to 3 to fill the depression and advance the entire shoreline seaward consistent with advancement of the beach fill on the updrift side of the first groin. By advancing the shoreline seaward within the groin compartments and adding sand volume into the system (particulary filling the scour trough seaward of cells 1 to 3), it is hoped to reduce beach erosion and scour due to wave and currents. After construction of the Federal project, monitoring of the demonstration project will focus on effectiveness of the Beachsaver Reefs and the Double-T submerged sill in retaining beach fill and thus reducing renourishment requirements for the Federal project.

Installation

The Beachsaver Reef structure was constructed first. For that installation, the rolled up geotextile mat was deployed by a barge-mounted crane (Figure 8). Once on the bottom, the mat was extended seaward by divers. Three interlocking Beachsaver Reef units were then placed on the seaward side of each geotextile mat with the use of the crane (Figure 9). Divers then aligned the placement of subsequent units and insured that the interlocking was accomplished. This linear submerged structure was tied into the groins on either end with the placement of rocks to make a completely enclosed perched beach in that cell, as was done in the 1994 project (Figure 10).

An initial survey in March 2002 indicated that the -2.7-m- (-9-ft-) contour was nearly parallel with the shoreline and the end of the groins. Just before construction, a new survey in June 2002 indicated that the -2.7-m- (-9-ft-) contour had moved seaward on the eastern one-third of the groin cell and landward on the western end. This change in bed elevation is believed to result from the strong flood currents seaward of the groins. These currents have caused frequent nearshore elevation changes. In order to maintain the desired depth of placement, excavation with a barge-mounted backhoe was required along the eastern portion of the line due to deposition of sand in the spring of 2002 (Figure 11). The orientation of the line of Beachsaver Reef units was angled slightly seaward to parallel the -2.7-m (-9-ft) contour. As the reef line reached the center of the cell, sand fill was required before the filter cloth was placed to bring the bed elevation up to the required depth. This lower bed elevation on the western side of the cell was due to: (a) natural scour in the spring months and (b) localized scour of the bed from the strong tidal currents flowing around each breakwater unit as it was

being placed. This scour was especially severe during the maximum flood tide as construction proceeded from east to west. The barge-mounted backhoe excavated the sand from the nearshore on the landward side of the placement line and filled along the placement line. This cut and fill increased the installation time. A new alignment was selected in the middle of the cell to bring the line more landward into shallower water to alleviate the requirement for fill and to intersect the seaward end of the west groin. The final alignment of the 72-unit reef had a seaward bow in the line (Figure 3) due to the change in bed elevation at the time of placement from the preinstallation survey 5 months before. Placement, originally scheduled for mid-June, was delayed to mid-August because of the mating of horseshoe crabs (*Limulus polyphemus*). The Beachsaver Reef installation was completed over 5 weeks from 16 August to 25 September 2002, a total of 25 working days.

The Double-T sill was designed to trap sand within the groin compartment as shown in Figure 12. This type of structure has never been used for erosion prevention and fits the nontraditional or innovative criteria under the Section 227 Program. Units were trucked to the staging site with the legs facing downward. The units were flipped when placed on the barge. The same barge and crane configuration were used as with the Beachsaver Reef installation. The crane was attached to the inverted legs and the unit lifted off the barge and placed on the bottom (Figure 13). Divers assisted in aligning and interlocking the units. Rods were temporarily placed on all four corners of the units to give the crane operator a sense of where the units were as it was lowered to the bed. Divers did the final positioning to interlock the ends of each unit. The sill units adjacent to the groins at each end of the line were filled with stone to attach the sill to the groin making a closed compartment.

Surveys of cell 6 in March and June 2002 indicated that the -2.7-m- (-9-ft-) NAVD contour was straight and parallel to the shoreline near the seaward end of the groins and did not change over time. No excavation or fill was needed to place these units at the desired depth. The sill was installed at an elevation of -2.7 m (-9 ft) mlw, at or near the seaward end of the stone groins. This location put the crest of the inverted Double-T at an elevation of approximately -1.8 m (-6 ft) mlw.

Preliminary designs did not anticipate any foundation or settlement problems with such a broad base (Peltz et al. 2004). With a length about three times that of the Beachsaver Reef units, 22 units were needed to span the 200-m (656-ft) width of the cell. No filter cloth was used as a base for the Double-T units. With no cut and fill needed and no filter cloth base used, installation took 4 working days to complete, between 26 September and 2 October 2002.

Cost

The Beachsaver Reef was installed over a period of 5 weeks. It is difficult to estimate a general cost of this type of unit due to problems with placement of the units on the seabed. Shoaling in the eastern end required excavation and scour on the west end required fill placement before the filter fabric and breakwater units

were placed. The 72 units needed to reach across the width of cell 5 brought the cost to an estimated $1,000 per linear foot for this Beachsaver Reef placement. This cost included the use of divers to align the units and assure proper interlocking.

Since this was the first installation of the Double-T sill structure, there is a lack of economy of scale in calculating a true construction cost. These units were completely installed in 4 days. The installation did not use filter cloth, and no excavation or fill was required. The 22 units needed to cover the width of cell 6 brought the estimated cost for the Double-T sill to $350 per linear foot, which included the use of drivers to align the units. The estimated cost of both structures did not include the cost of rock used to tie the structures into the groins.

2 Monitoring Plan

Project Design

The monitoring program was designed to measure performance of the two prefabricated, concrete, submerged breakwaters in three performance areas (functional performance, economic performance, and structural performance). This site was chosen for a Section 227 demonstration project because of its history of erosion, available baseline data including the two existing Beachsaver Reefs, and the availability of the new Beachsaver Reef and Double-T sill devices. The complex nature of interaction between wave and tidal forces at this site have required nontraditional approaches to retaining sand on these beaches.

The Beachsaver Reef is considered a narrow-crested structure because of the triangular shape with the smallest dimension at the crest width. The unit is placed with its longer, flatter sloping face seaward and the steeper shorter sloping face facing the beach. The raised crest area was originally designed to trip the incoming wave as it passed over the unit. The steeper slope on the landward side was designed to cause return flow under the breaker to be forced upward to enhance the wave tripping mechanism and any sand placed in suspension to be transported back onto the beach. Sand is supposed to be trapped on the shoreface preventing it from flowing offshore. Previous experience in cells 2 and 3 with the Beachsaver Reef indicated some success in retaining sand within the compartments, but settlement had rendered these structures less effective in wave attenuation. To improve the design, a filter cloth with a concrete filled bag anchor was added to the new project to help prevent this settlement. The Section 227 project will evaluate this new design configuration.

The Double-T sill is designed to act as a sill, trapping sand that is transported offshore under the waves as bed load and near bottom suspended load. The sand should be retained on the landward side of the two inverted legs and remain within the groin cell. This is an innovative shore protection application that has not been demonstrated previously. The Section 227 project will evaluate this new sill type structure as a relatively low-cost erosion prevention device.

Five components are to be included in the monitoring plan to document the three categories of performance: (a) dune, beach, and nearshore profile surveys, (b) structure specific settlement and scour measurements, (c) sediment sampling, (d) wave and current measurements, and (e) aerial photography.

Functional performance

The functional performance is defined as how well the structures retain sand on the beach. To measure this sand retention, the monitoring includes a measure of the change in sand volume on the beach profile and the change in dry beach width as measured by the position of the shoreline (defined as the mean high water (mhw) line) over time. An understanding of wave and tidal forces and how they interact with each structure is also needed to assess the sand retention properties of each structure.

Economic performance

The economic performance is defined as how well the structures reduce the renourishment quantities required after a beach fill is placed on the beach and if the fill cycle can be extended because of the entrapment of the fill sand behind the structures over the long term. Any extension in the renourishment cycle-time will provide a cost savings and extend the storm damage reduction abilities of this type of project configuration. Assessment of sand volume retention, shoreline position stability, and fill sediment grain-size distribution change will be evaluated with the monitoring data.

Structural performance

The structural performance is defined as how well the structural integrity of each type of structure is maintained over time. Did the structure maintain its crest elevation, its alongshore integrity, or cause scour at its base over time and lose the ability to function as designed? Measurement and evaluation of structural settlement, rotation and position stability of the individual structural units, and scour hole formation will be included in the monitoring.

Beach Profile Surveys

A total of 29 profiles of topography and bathymetry were surveyed in the eight groin cells. In each cell, profiles were measured at an alongshore distance of 30.5 m (100 ft) from the groins that define each cell. Three profile lines were established and surveyed in groin cells 1, 2, and 3, with the additional profile line being located midway between the two outer lines. Four profile lines were established in cells 4 through 8 with the two additional profile lines located at approximately equal intervals between the outer lines (Figure 14 and Table 1). The first profile line on the east side was CMP19 and the last line on the western cell was CMP47.

Table 1
Location of Profile Lines Within Groin Cells

Cell No.	Location	Profile No.	Azimuth	Comments
1	Lighthouse Ave. to Leigh Ave.	CMP19	N 180°47'00.56" E	Rock Revetment No dry beach
		CMP20	N 186°51'58.17" E	
		CMP21	N 192°54'02.27" E	
2	Leigh Ave. to Willdin Ave.	CMP22	N 192°49'40.32" E	1994 Beachsaver Reef #1 Gabion Revetment
		CMP23	N 199°02'16.48" E	
		CMP24	N 205°08'31.98" E	
3	Willdin Ave. to Coral Ave.	CMP25	N 205°07'51.98" E	1994 Beachsaver Reef #2 2000 Beach Fill
		CMP26	N 208°54'42.93" E	
		CMP27	N 212°39'43.62" E	
4	Coral Ave. to Ocean Ave.	CMP28	N 212°35'32.87" E	Control 2000 Beach Fill 2004 Beach Fill
		CMP29	N 214°23'22.30" E	
		CMP30	N 216°12'19.87" E	
		CMP31	N 217°54'34.06" E	
5	Ocean Ave. to Cape Ave.	CMP32	N 217°54'43.28" E	2002 Beachsaver Reef (Section 227) Gabion and Rock Revetment
		CMP33	N 223°03'31.06" E	
		CMP34	N 228°12'34.85" E	
		CMP35	N 233°16'28.37" E	
6	Cape Ave. to Central Ave.	CMP36	N 233°10'08.38" E	2002 Double-T sill (Section 227)
		CMP37	N 236°49'33.05" E	
		CMP38	N 240°20'58.53" E	
		CMP39	N 243°55'57.17" E	
7	Central Ave. to Stites Ave.	CMP40	N 243°54'00.18" E	Control
		CMP41	N 244°59'27.47" E	
		CMP42	N 246°07'58.35" E	
		CMP43	N 247°12'59.40" E	
8	Stites Ave. to Alexander Ave.	CMP44	N 247°11'08.32" E	Control
		CMP45	N 248°17'53.52" E	
		CMP46	N 249°34'16.45" E	
		CMP47	N 250°41'53.90" E	

Profiles were established at a project-specific set of semipermanent benchmarks (concrete post or metal pipe with survey disc) located along the roads that parallel the beach behind the dunes. The surveys were collected relative to New Jersey State Plane Grid Coordinates (NAD83) with a vertical datum of NAVD88. Each profile line extended from the benchmark located behind the dune line seaward for a distance of 152 m (500 ft) (short line surveys for preconstruction data) or 1,524-m- (5,000-ft-) long line surveys for area-wide coverage). Front benchmarks were established behind the dunes for each profile line and a compass bearing was established in each line to ensure that the lines can be resurveyed for at least a 3-year monitoring period. The profiles over the dune were measured with a Global Positioning System (GPS) survey system. Beach and foreshore surveys to wading depth were measured with either the GPS system or a total station and survey rod method (Figure 15). A boat/fathometer survey continued the line seaward to measure the nearshore inside the cells as well as the marginal

flood channel and shoals further offshore. The profiles started at the landward side of the dune with measurements of the dune crest, seaward side base, and out to wading depth at the groin seaward tip. The boat/fathometer survey continued with overlap of at least 15 m (50 ft) to about 1,524 m (5,000 ft) seaward of the groins tips. The overlap provided a check of the match between the two methods. On average, the match was within 0.3 m (1 ft). In cells with the sill or submerged breakwater (cells 2, 3, 5, and 6), elevations at the landward toe, crest, and seaward toe of the sill or breakwater unit were measured where the profile line crossed the structure.

Preinstallation profiles were collected in July 2000 and January 2001 of the 29 profile sites within the study area. The initial project bathymetric survey of cells 5 and 6 were collected in January 2002 and the 29-line survey of the entire Cape May Point beach area was collected in March of 2002 to characterize the preconstruction bathymetry. An additional detailed survey was collected in June 2002 in cells 5 and 6 prior to construction of the new structures to determine placement options and locations. A full preinstallation survey was conducted in August 2002 just before installation, but positioning and datum problems between the wading and boat data limited the use of this data set.

Postinstallation surveys were scheduled quarterly. Contractual and funding problems precluded obtaining a bathymetric survey immediately after installation. The first scheduled postinstallation survey was January 2003, but ice buildup on the beach and ice floes in the nearshore made surveying impossible (Figure 16). The first survey was obtained in April 2003 to document the changes in the bed elevation. Surveys were collected in July 2003 and October 2003 following the quarterly survey schedule (Table 2).

Table 2
Project Monitoring Components and Time Line

Date	Profile Surveys	Settlement Surveys	Sediment Sample Collections	Wave and Current Measurement, sec	Aerial Photographs
July 2000	☑				
January 2001	☑				
January 2002	☑				
February 2002	☑ Cell 5 and 6 only				
March 2002	☑				
April 2002			☑		☑
July 2002	☑ Cell 5 and 6 only		☑		
August 2002	☑				
October 2002		☑			
April 2003	☑	☑			
July 2003	☑	☑	☑	☑	
October 2003	☑	☑			☑

Monitoring beach profile evolution will measure shoreline change. Bathymetric changes using two-dimensional (2-D) profile analysis software will measure sediment volume change, an indicator of how much sediment is retained behind the test structures relative to the control cells. Three-dimensional (3-D) bathymetric change analysis in a Geographic Information System (GIS) will provide patterns of sediment change and measure both profile sand volume retained and shoreline evolution.

Bathymetric change

For each survey, the 29 profile lines were entered into an ArcView GIS. Each data set was transformed into a triangulated irregular network (TIN) model and contoured to provide a digital elevation model (DEM). The bathymetry shows a flood channel located just seaward of the groins with a scour hole up to 18 m (60 ft) deep off the first two groins. This trough gradually shoals to the west and intersects a dynamic and changeable shoal just seaward of cells 5 and 6 (the location of the two Section 227 structures). This northwest-southeast trending linear shoal corresponds to the area of flood and ebb flow intersection at the mouth of the bay (Figure 17). Difference maps were created between each survey date in the GIS to measure the pattern of change between surveys.

Shoreline change

The shoreline is defined as the mhw line, which is 0.61 m (1.99 ft) above NAVD88 relative to the closest tide gage, 3.8 km (2.4 miles) north of the study site at Cape May Canal. Shoreline changes are measured in two ways. The first is to find the mhw intersection on each profile and fit an isograd to the mhw points in the GIS. Each survey date produces a shoreline position based on the profiles. The second is to digitize the wet/dry line on available rectified aerial photography. This line is readily visible on the photography and is usually lower on the profile than the mhw line. Figure 18 shows the two lines on an oblique photograph of the beach.

The horizontal spatial changes of the mhw line and volume along the beach are analyzed using the Beach Morphology Analysis Package (BMAP) interactive computer program (Sommerfield et al. 1994). The shoreline change analyses measures the position of the mhw contour relative to a common baseline for each survey date. This analysis provides a relative movement of the mhw line either landward or seaward from its previous position but does not represent changes in the sand volume or morphology over time. The change in mhw line is an indicator of long-term general sediment movement and is used to depict shoreline retreat or advance.

Beach volume change

The BMAP software was used to analyze volume change between profile dates. Volumetric changes between the July 2000 preplacement baseline and the subsequent monitoring surveys were determined using BMAP, which can

determine the volume gain or loss between two profiles. The volume change analysis was calculated within each profile envelope between a fixed point on the dune close to the crest seaward a fixed distance into the nearshore about the same distance seaward as the seaward end of the adjacent groin. Gain or loss of sand volume represents the change in either erosion or accretion between any two dates for a fixed area along each profile. The change in volume of sand on the active profile is an indicator of how much sand in either added to the profile or removed from the profile by the prevailing coastal processes. Volume retained or lost behind the breakwater structures is a measure of how successful the structures are in preventing erosion.

Settlement and Scour Measurements

Settlement and vertical and horizontal alignment of the Beachsaver Reef and Double-T sill will be evaluated to determine their structural stability. Settlement occurred within the first 3 months following installation for other prefabricated, narrow-crested, submerged breakwaters (Stauble and Tabar 2003). Scour at the base of the units will be monitored by carefully surveying the seaward and landward base of the units to detect any scour hole formation or realignment. Past projects showed a tendency for these types of breakwater units to form a scour trough (particularly along the entire length of the landward side and intermittently along the seaward side) and lose some of their structural stability. The result was settlement and rotating of the units into the scour trough.

Settlement

Elevation measurements are taken along the crest of each sill/breakwater structure to determine settlement. Measurements are made concurrently with beach profile surveys (Figure 19). The top of the Beachsaver Reef was measured at the crest of the unit.

As each Beachsaver Reef unit was placed, detailed measurements were made of the top of each unit and its orientation as placed to provide an as-built elevation. The Beachsaver Reef units were placed between 16 August and 25 September 2002. A complete postconstruction survey was obtained of all the Beachsaver Reefs on 7 October 2002 and was considered the first postconstruction survey for the Beachsaver Reef (a little less than 2 weeks after the last Beachsaver Reef was installed).

The top of the Double-T sill was measured on top of the seaward vertical leg. The first settlement survey of the Double-T sill unit crests was made after final placement of the last Double-T unit on 7 October 2002. Since the Double-T sill only required 4 days to be installed (between 26 September and 2 October 2002), only a single survey of the tops of these units was done. This survey was considered the as-built survey for the Double-T. Subsequent surveys of the tops of the structures were done during profile survey times in April, July, and October 2003.

Scour

In cells with a sill or submerged breakwater (cells 2, 3, 5, and 6), particular attention was paid to accurately determine elevations at the landward toe, crest, and seaward toe of the sill or breakwater unit. Detailed measurements in the vicinity of the structures during wading profile surveys were used to determine the scour trough development.

Scour and settlement surveys were obtained in April, July, and October 2003 for the first year of monitoring along with the beach profiles. Scour, settlement, and reorientation are documented to evaluate the project's structural stability. Excessive changes in the elevation, orientation, and scour at the base of both types of units may affect their ability to retain sand. The new geotextile fabric layer is being evaluated as to its effectiveness in preventing scour and settlement of the Beachsaver Reef.

Sediment Characteristics

Beach sand samples were collected before construction in July 2002 and during the summer survey following construction in July 2003 to document any change in grain-size distribution. The Cape May Point beach is composed of fine sands with some coarse, gravel size material. A higher concentration of this coarse material is found on the beaches in the western cells, possibly reflecting a change in the processes from the ocean to the bay and/or the underlying geology. If these breakwater structures retain sand in the perched beach concept, it is hypothesized that the grain-size distribution change within these cells will be different from the more open cells. After nourishment, it is suspected that the fill grain size will resort itself as it usually does on an open beach, and the monitoring will document the effect the structures have on extending the time line and reducing the volume requirements for renourishment.

Sampling design

Grab samples were collected along the profile lines at the time of the beach survey. Samples were planned to be collected at the dune base, berm crest/high-water line, midtide, swash/low-tide line, and at the -0.91-m (-3-ft) and -1.83-m (-6-ft) location inshore of the structures and seaward of the structures at -2.7-m (-9-ft) mlw contour. Due to limits in time and budget, sample numbers and locations were modified to include 13 of the beach profile lines. Samples were collected on one of the middle profiles on each cell compartment except for the project cells 5 and 6, where samples were collected on each of the four profile lines. The sample locations were surveyed in using the total station/rod to document the location (Figure 20). The beach samples were collected by a scoop, at the base of the survey rod along the profile line for accurate positioning of the samples. Offshore samples were collected by a Ponar grab sampler from the survey boat using GPS positioning.

Two grab samples were collected in April 2002 at the midtide location in cells 5 and 6 as a preliminary measure of the native grain-size distributions in the

two test cells on a winter beach. Thirty-nine preinstallation samples were collected by Stevens Institute of Technology in July 2002 at high tide (HT), midtide (MT), and in the nearshore (NS), which was about half way between the low-tide line and the proposed location of the structure. The full 65 sample postinstallation set was collected by Stockon College in July 2003 on the same 13 lines as the preinstallation samples (Figure 21). These samples were collected at the berm crest/high-water line (HT), MT, and the swash/low-water line (LT), inshore of structures at the -1.83-m (-6-ft) contour (NS) and offshore of the structure at the -2.7-m (-9-ft) contour (OS).

Grain-size analysis

The preinstallation grain-size analysis was conducted at CHL. The postinstallation sample laboratory grain-size analysis was conducted at Stockton College. Sediment samples were analyzed for grain-size distribution using quarter-phi sieves. The preinstallation samples were sieved with a sonic sifter and the postinstallation set was sieved with a standard rotap. Tests indicate that both methods give similar results (Underwood and Frye 1988). The preinstallation samples were analyzed by CHL Interactive Sediment Analysis Program (ISAP), which calculates mean, median, standard distribution (sorting), skewness, and kurtosis using the method of moments. Data from the postinstallation sediment analysis included mean, median, mode, standard deviation, skewness, and kurtosis using the Folk graphic method. The statistics were recalculated using the method of moments using the GRADISTAT software program to provide a common dataset (Blott and Pye 2001). The method of moments uses the entire grain-size distribution data set (27 sieves) and provides a more accurate calculation of the statistics than the graphic method, which is limited to three to five data points. Changes in sediment size will be evaluated between preinstallation distributions and at 1-year intervals and be related to profile changes and the sediment retention capability of the two structures.

Sediment cores

A series of five cores was collected in 2000 and 2001 to assess foundation conditions for the two breakwaters (Figure 21). A long split-spoon core was taken from a barge on 4 October 2000 at the west end of cell 6. The core was 11.0 m (36 ft) long and was collected in 2.32 m (7.6 ft) of water mllw. Four short Electric Rossfelder P-3 cores were taken on 19 June 2001 to document the shallow subbottom sediment along the rest of cell 5 and 6. These cores ranged from 2.32 to 1.37 m (7.6 to 4.5 ft) in length and were collected in water depths ranging from -0.95 to -1.68 m (-3.1 to -5.5 ft) mllw.

Waves and Currents

Wave transmissions across the two breakwaters were measured. The difference in orientation of the two cells with structures (cells 5 and 6) and the control cell (cell 4) along with the presence of shoals seaward of both cells may influence the interaction of waves and tidal currents. Visual observations prior to

installation indicate a rip current along most of the groins. Visual observations of ice floes around the cape on a flood tide in March 2003 after installation of the structures indicated that ice was trapped in cell 5 behind the Beachsaver Reef and the circulation in both cells 5 and 6 were more circular in the center of the groin compartments. Both the Beachsaver Reef and Double-T sill elevations were lower in the center by about 0.31 to 0.61 m (1 to 2 ft) of their respective lines at time of placement and may be influencing circulation in their groin compartments. The rock tying in the structures to the ends of the groins may be inhibiting formation of the near-groin rip currents observed before installation.

Wave gages

Four wave gages were deployed from 14 to 17 July 2003 to measure wave height and period and wave transmission changes over the submerged breakwaters. A bottom-mounted tripod with a nondirectional pressure gage was placed in each of three cells. A gage was placed on the landward side of the Beachsaver Reef in cell 5, the landward side of the Double-T sill in cell 6, and inside the control cell 4, each at a depth of about 1.8 m (6 ft). A directional gage (SonTec ADV) was placed outside of the groin compartments off the Beachsaver Reef cell 5 in -6.1 m (-20 ft) of water (Figure 22). The deployment was for about 60 hr with simultaneous recording at all four gages. Figure 22 shows the tripod mount of the inshore nondirectional pressure gages. The nearshore SonTec ADV gage was mounted on a plate lowered to the bottom in the trough offshore of the groin field. Due to extraordinary noise in the time series of the ADV gage, incident wave direction was not determined. The mean water-surface elevation was estimated from the pressure time series adjusted using atmospheric pressure data recorded by an atmospheric pressure gage on land.

NOAA Buoy 44009, a nondirectional wave gage, located in 28 m (92 ft) of water 26 n.m. southwest of Cape May, NJ, was compared with the four gages. Offshore wave heights were relatively constant (around 0.8 m or 2.6 ft) for most of 14 and 15 July. Wave height increased during 16 July 2003 to a maximum of about 1.2 m (4 ft) with the passage of a cold front. Water level data were measured by each gage to record tidal height. Figure 23 shows the water level and wave heights from the NOAA gage and the four study gages during the 60-hr deployment period.

Acoustic Doppler Current Profiler

Currents were measured with a 1,200-kHz and a 600-kHz acoustic frequency BroadBand Acoustic Doppler Current Profiler (BroadBand ADCP), manufactured by RD Instruments of San Diego, CA. These instruments measure current velocities by transmitting pulses of sound and measuring the Doppler shift of reflected sound off of suspended matter in the water column (Pratt and Stauble 2001). This assumes that particles are moving at the same velocity as the water. By time-gating the returned signal and knowing the speed of sound in water, the BroadBand ADCP associates different periods in the returned signal with different ranges in depth (bins). The water velocity for these depth bins can then be calculated. TRANSECT software provided by RD Instruments, on a laptop

computer, enabled raw current data to be interfaced with the Differential Global Positioning System (DPGS). This software can replay raw data and convert it to ASCII format.

ADCPs have a vertical resolution of 0.5 m. The measurements are made remotely at regular intervals of time and space throughout the water column, thus generating a cross-sectional current profile. The advantage of BroadBand ADCP is that the survey boat does not need to be stationary during the measurement process. The instrument subtracts vessel motion from the raw data to produce earth-referenced current vectors.

The ADCP was mounted on the side of the CHL survey boat *Mr. Dave* using specially designed mounts. The level of the instrument was adjusted to keep it in the water at all times. Five transects were collected during July 2003 to identify circulation patterns outside of the groin compartments and along the cells at the groin tips to determine changes in flow patterns (Figure 24). The ADCP was mounted on the side of the boat and positioning was done using a time-linked GPS. Three hourly runs were done on the ebb and flood to measure both directions of tidal currents. Four of the transect lines corresponded with the profile survey lines and were chosen to capture the flow conditions around the point. The line parallel to the beach was designed to capture any circulation in and out of the groin compartments and in front of the submerged structures.

Aerial Photography

Uncontrolled vertical black and white aerial photographs of other Philadelphia District coastal projects are typically obtained on a quarterly basis. Photographs specific to this project will be obtained as part of this regular coastal photography. A scale of 1:4800 was, using 23 × 23 cm (9 × 9 in.) negatives will be used.

Photographs collected during the monitoring period include color orthophotographs taken May 2002, October 2002, and October 2003. Oblique aerial photographs were taken on 17 September 2003 (pre-Hurricane Isabel), and on 3 March 2004.

3 Data Analysis

Analysis of this first year's monitoring includes pre-and postinstallation profiles, postinstallation settlement surveys, pre- and postinstallation sediment samples, limited postinstallation wave gage data and current measurements, and pre- and postinstallation aerial photography.

Shoreline Change

The shoreline for this study is defined as NOAA's tidally derived mean high water elevation line (the +0.60 m (+1.99 ft) NAVD88 contour). Based on the first available profile set for this area (July 2000), cell 1 had no dry beach and the shoreline position could not be monitored since water was up against the rock revetment at all stages of the tide (Figure 25). Cell 2 (containing the 1994 Beachsaver Reef and dune base rock and gabion revetment) had a relatively wide intertidal beach with the shoreline abutting the revetment at the eastern end and some dry beach at the western end (Figure 26). Analysis compared the change in the distance of the mhw contour relative to the baseline of the dune toe between profiles. The analysis showed a seaward movement during the first 2 years and a landward movement in 2003. A general seaward movement was measured in July and October 2003 (Figure 27). Table 3 shows the cumulative shoreline change measured as change in the mhw line of July 2000 relative to each profile date.

Placement of the beach fill (December 2000 to January 2001) in cell 3 moved the shoreline seaward 12 m (40 ft). Cell 3 contains the second 1994 Beachsaver Reef installation. Figure 28 shows the width of the dry beach in this cell. After readjustment of fill over the first year, the shoreline retreated about 6.1 m (20 ft) and has been relatively stable in that position from March 2002 to October 2003.

Cell 4 (the eastern control cell) also received beach fill sand in January 2001. The shoreline advanced to over 15 m (50 ft) as of the January 2001 survey. Figure 29 shows the dune and berm configuration in cell 4. The shoreline retreated landward 6 m (20 ft) as the fill readjusted in 2002. Landward retreat continued over the study period, with a net movement of -1.2 m (-4 ft) relative to the prefill 2000 shoreline on the western most profile line. Sand has been observed flowing over the landward sections of the groin into cell 5 during high water.

Table 3
Cumulative Shoreline Change at Cape May Point 227 Project Distance from Dune Base to mhw (1.99 ft Using 83-01 Tidal Epoch)

Cell & Profile No.		Type of Back Beach	2000/07 to 2001/01 (ft)	2000/07 to 2002/03 (ft)	2000/07 to 2003/04 (ft)	2000/07 to 2003/07 (ft)	2000/07 to 2003/10 (ft)
Cell 1	CMP19	Rock	0	0	0	0	0
	CMP20	Rock	0	0	0	0	0
	CMP21	Rock	0	0	0	0	0
Cell 2	CMP22	Rock	1.82	-2.32	3.83	-2.07	-0.87
	CMP23	Gabion	29.01	28.24	7.59	16.75	16.14
	CMP24	Gabion	20.08	14.39	5.35	9.86	11.87
Cell 3	CMP25	Dune	44.29	27.91	23.35	28.90	22.72
	CMP26	Dune	37.11	20.10	16.20	20.14	19.63
	CMP27	Dune	35.50	24.92	22.83	20.24	24.25
Cell 4	CMP28	Dune	52.35	27.96	6.51	7.99	11.08
	CMP29	Dune	55.15	34.16	10.12	8.83	14.37
	CMP30	Dune	41.18	24.03	9.50	5.83	7.45
	CMP31	Dune	25.77	6.79	3.62	1.18	-4.11
Cell 5	CMP32	Rock	1.47	7.33	7.10	0.79	13.49
	CMP33	Rock	-2.28	-1.27	1.28	-2.03	5.38
	CMP34	Gabion	-2.28	7.06	22.11	16.95	21.29
	CMP35	Gabion	-3.26	0.71	46.21	32.87	29.69
Cell 6	CMP36	Dune	35.73	-5.45	-14.64	-15.78	-17.48
	CMP37	Dune	9.04	-17.91	-23.18	-18.27	-18.62
	CMP38	Dune	-8.33	-15.36	-19.34	-14.03	-20.88
	CMP39	Dune	-15.79	-0.03	-5.88	-19.57	-16.76
Cell 7	CMP40	Dune	52.46	44.37	14.34	-10.70	7.17
	CMP41	Dune	17.28	19.22	-0.97	-10.81	-8.19
	CMP42	Dune	-25.11	-9.54	-2.82	-6.30	-19.95
	CMP43	Dune	-51.49	-23.67	-2.07	-17.92	-37.31
Cell 8	CMP44	Dune	89.33	57.28	26.70	-6.41	-7.52
	CMP45	Dune	32.51	13.31	-2.85	-7.71	7.53
	CMP46	Dune	-59.89	-42.91	-18.40	-4.25	-9.97
	CMP47	Dune	-108.78	-76.17	-28.64	4.09	-24.00
Average Shoreline Change by Cell							
Cell 1			0.00	0.00	0.00	0.00	0.00
Cell 2			16.97	13.44	5.59	8.18	9.05
Cell 3			38.97	24.31	20.79	23.09	22.20
Cell 4			43.61	23.24	7.44	5.96	7.20
Cell 5			-1.59	3.46	19.18	12.15	17.46
Cell 6			5.16	-9.69	-15.76	-16.91	-18.44
Cell 7			-1.72	7.60	2.12	-11.43	-14.57
Cell 8			-11.71	-12.12	-5.80	-3.57	-8.49

The shoreline in cell 5 was initially retreating, but the western two profiles have shown an advance of the shoreline since the Section 227 Beachsaver Reef was installed. Figure 30 shows the rock and gabion revetment installed in 2001 to protect the dunebase in this cell. On the east side of the cell, the shoreline is at

the base of this revetment. There is more dry beach on the western side of the cell. The shoreline advanced to its seawardmost point of 14 m (46 ft) on the western side of the cell after installation of the new Beachsaver Reef. As of October 2003, the shoreline has retreated back to 9 m (30 ft) seaward relative to the 2000 survey. This cell shows a trend of seaward movement on the western end (opposite of cell 4, which showed the shoreline position change to be more seaward on the eastern end of the cell).

Cell 6, with the Double-T sill, has a history of shoreline retreat for the entire study period starting before the Double-T sill was installed. The mhw shoreline moved landward of the July 2000 shoreline, by about 6 m (20 ft). Figure 31 shows the narrow dry beach, with a relatively wide intertidal area in this cell.

Cells 7 and 8 (western control cells) behaved alike. The shoreline is rotating with an original seaward movement of the eastern end of the cell and retreat on the western end of the cells. This pattern has changed over the course of the study with a more uniform change along the shoreline. The western shoreline has retreated while the eastern shoreline position has advanced. As of July 2003 the shoreline position was just landward of its July 2000 position in both cells. As of October 2003, the shorelines reversed again and are advancing on the eastern end and retreating on the western end. Figures 32 and 33 show the position of the shorelines in these two bayside cells, with most of the dry beach in the western ends of the compartments. They appear to be oscillating in response to a seasonal or longer change in wave direction.

Beach Volume Change

Beach volume was calculated using BMAP. Volume differences between two profiles were calculated from the dune out to the approximate ends of the groins in cells with no breakwaters (cells 1, 4, 7, and 8) or to the landward end of the breakwater structure (cells 2, 3, 5, and 6). Each profile has different landward and seaward end points, but the same length was used when computing sand volume change for each profile.

Table 4 lists the length of each profile and the cumulative volume change between the first preproject surveyed (July 2000) and each successive survey. One profile was chosen for each groin compartment to be representative of the volume changes within each one. The representative profile was one of the center profiles away from the influence of the groins.

Cell 1 is backed by the rock revetment and has no dry beach. Profile CMP20 in the center of the cell shows a volume loss between July 2000 and April 2003. A volume gain was measured between July and October 2003. Figure 34 shows the pattern of change within the subaqueous beach within the groins. Just seaward of the groins, a scour hole is present that reaches to approximately 17 m (55 ft) deep. The recent gain in sand volume appears to be on the seaward portion of the groin compartment seabed, just landward of the scour hole.

Table 4
Cumulative Volume Change at Cape May Point 227 Project

Groin Cell No.	Profile No.	Distance from Dune to Structure (ft)	2000/07 to 2001/01 (cu yd/ft)	2000/07 to 2002/03 (cu yd/ft)	2000/07 to 2003/04 (cu yd/ft)	2000/07 to 2003/07 (cu yd/ft)	2000/07 to 2003/10 (cu yd/ft)
Cell 1	CMP19	270 to 575 = 305	14.16	45.78	-17.66	-24.68	11.34
Seawall	CMP20	350 to 685 = 335	-3.57	-6.34	-10.79	-3.81	6.05
	CMP21	130 to 520 = 390	-18.82	-26.35	-33.08	11.49	-10.02
Cell 2	CMP22	110 to 440 = 330	0.45	7.43	7.43	4.90	6.11
1994 Beachsaver 1	CMP23	056 to 522 = 346	1.64	13.52	4.81	9.27	8.77
Gabion and Rock	CMP24	068 to 549 = 481	-1.14	13.69	6.31	5.75	7.01
Cell 3	CMP25	115 to 527 = 412	16.50	15.23	14.80	9.16	12.20
1994 Beachsaver 2	CMP26	115 to 525 = 410	8.87	10.47	9.21	9.92	7.46
2000 Beach fill	CMP27	149 to 528 = 379	1.39	5.12	7.97	7.01	4.08
Cell 4	CMP28	147 to 540 = 393	15.69	9.92	6.80	8.37	13.98
Control	CMP29	114 to 513 = 399	15.26	9.11	2.06	8.18	8.80
2000 Beach fill	CMP30	125 to 516 = 391	6.77	4.81	-0.23	2.94	-1.41
	CMP31	300 to 707 = 407	-2.85	-4.40	-2.31	1.28	-3.60
Cell 5	CMP32	295 to 728 = 433	0.02	17.13	23.93	23.08	30.90
Gabion and Rock	CMP33	229 to 711 = 482	-8.54	11.75	14.98	19.91	21.04
227 Beachsaver	CMP34	191 to 682 = 491	-13.01	7.55	20.62	22.09	19.52
	CMP35	146 to 560 = 414	-18.42	-1.45	17.72	11.46	10.28
Cell 6	CMP36	081 to 487 = 406	6.55	2.67	-6.38	1.89	0.60
227 Double-T	CMP37	277 to 700 = 423	-1.51	-3.60	-11.23	2.96	3.33
	CMP38	261 to 688 = 427	-9.23	0.35	-5.62	1.99	6.90
	CMP39	295 to 678 = 383	-11.60	7.16	3.92	0.66	6.60
Cell 7	CMP40	248 to 678 = 430	11.61	10.14	2.94	-2.50	-8.06
Control	CMP41	192 to 657 = 465	5.66	9.62	1.11	0.67	-5.75
	CMP42	262 to 735 = 473	-20.55	-8.65	-6.73	-3.82	-8.73
	CMP43	340 to 760 = 420	-25.33	-8.78	-0.38	-8.81	-15.56
Cell 8	CMP44	185 to 553 = 367	32.95	20.08	11.36	1.54	1.03
Control	CMP45	142 to 545 = 403	17.86	11.67	1.20	-2.41	1.81
	CMP46	167 to 525 = 358	-26.15	-14.72	-7.72	-1.81	1.06
	CMP47	200 to 505 = 305	-45.53	-27.78	-7.15	7.10	1.35
Average Volume Change by Cell							
Cell 1		343	-2.74	4.36	-20.51	-5.66	2.46
Cell 2		386	0.32	11.54	6.18	6.64	7.30
Cell 3		400	8.92	10.28	10.66	8.70	7.91
Cell 4		398	8.72	4.86	1.58	5.19	4.44
Cell 5		455	-9.99	8.75	19.31	19.13	20.44
Cell 6		410	-3.95	1.64	-4.83	1.88	4.36
Cell 7		447	-7.15	0.58	-0.76	-3.61	-9.52
Cell 8		358	-5.22	-2.68	-0.58	1.11	1.31

The 1994 Beachsaver Reef #1 in cell 2 has a scour trough about 1.2 m (4 ft) deep on its landward side. The center profile CMP23 (Figure 35**)** shows a gain of almost 22 cu m/m (8.8 cu yd/ft) between July 2000 and October 2003. The sand has moved from the upper beach to just in front of the breakwater. The gabion placed at the dune base has trapped sand on that part of the profile.

Cell 3 (second compartment of the 1994 Beachsaver Reef), had a net gain in sand of 18.8 cu m/m (7.5 cu yd/ft) between July 2000 and October 2003. Figure 36 shows the change in elevation in Profile CMP27 (middle of cell 3). There is also a scour trough about 1.2 m (4 ft) deep on the landward side of this structure. The beach fill berm, placed in January 2001, can be seen in the January 2001 and March 2002 surveys. It is not visible in subsequent profiles. Approximately 7.6 cu m/m (3 cu yd/ft) of sand was lost from this profile between March 2002 and October 2003.

Cell 4 (control) also had a beach fill in January 2001. Profile CMP29 (Figure 37) shows a similar loss of the fill berm over the same period as in cell 3. There is a net loss of fill of about 16.2 cu m/m (6.5 cu yd/ft) along this profile from January 2001 to October 2003, about twice the loss experienced by cell 3.

The first year monitoring analysis of the profiles in cell 5 (containing the Section 227 Beachsaver Reef) indicates that the breakwater is holding the sand in the compartment (Figure 38a). Figure 38b shows the general trend of sand being trapped inshore of the structure on profile CMP 33. The preinstallation profile (March 2002) showed a flat sloping profile. Six months after placement (April 2003), a sand gain was measured just inshore of the structure. As found in previous studies (Stauble and Tabar 2003) a scour trough was formed at the landward base of the structure. The new filter cloth scour blanket has not been effective in preventing the trough from forming. One year after construction, scour trench depths of -2.7 to -4.6 m (-9 to -15 ft) were measured in cells 2 and 3 (Harrington et al. 1997). Present monitoring of cells 2 and 3 of the established Beachsaver Reef installation shows a scour trench between -0.61 to -0.91 m (-2 to -3 ft) deep. The Section 227 Beachsaver Reef in cell 5 averaged a scour depth of approximately -0.76 m (-2.5 ft) on its landward side, comparable to the older, existing structures.

Nine months following installation (July 2003) additional sand was measured on the inshore side of the structure with a gain of approximately 53 cu m/m (21 cu yd/ft) of beach on line CMP33. As of October 2003, the profile showed a continued gain in sand with the same pattern. This profile is representative of the two eastern profiles in cell 5. Figure 38c shows a gain in sand volume of about 50 cu m/m (20 cu yd/ft) over the first 12-month monitoring for the west profile CMP34. The Beachsaver Reef has settled in this part of the cell, but still traps sand. The top of the structure is much lower and trapped sand is much closer to the crest of the structure here. The gain in sand is limited to the area just landward of the structure but shows no significant gain of sand on the upper beach or change in the shoreline.

The profile change in cell 6 (Double-T sill) during the same period was different. As will be discussed in the next section, the Double-T sill units settled about 1.22 m (4 ft) within the first 6 months following installation on profile line

CMP37 (Figure 39a) representing the eastern half of the cell. Settlement lowered the profile in the vicinity of the sill with only a gain in volume of 7.5 cu m/m (3 cu yd/ft). The sill had settled into the bed, was covered with sand and not visible in the profile. Twelve months after placement, a sand mound had formed just landward of where the structure is buried (Figure 39b). A gain in volume of 17 cu m/m (7 cu yd/ft) was measured on profile CMP38 (Figure 39c) landward of the structure at the western end of the cell. Twice as much sand is being trapped on the western end of the cell where the sill has settled the least. There appears to be a shift of sand within this compartment with less gain in sand volume on the eastern side and more gain on the western side relative to the preproject beach.

It is unclear at this time how the Double-T sill has settled and been covered by sand. No evidence is found for slumping or sliding. Sand has accreted just landward of the buried structure, and overall there is only a slight gain of sand in this cell from the preinstallation condition. Profiles CMP37 and CMP38 are representative of the beach profile response in cell 6 which averaged a relatively small gain in sand volume (comparable to the control cell 4) and the greatest shoreline retreat.

Cell 7 (the western control) experienced sand loss of about 14.4 cu m/m (5.75 cu yd/ft) following the July 2000 survey on profile CMP41. Erosion was in the vicinity of the berm (Figure 40a). A loss of 21.8 cu m/m (8.7 cu yd/ft) was measured on profile line CMP 42. This control cell appears to be losing more sand from its eastern side since the berm is less eroded on profile line CMP42 (Figure 40b).

The last cell to the west, fronting more on Delaware Bay, experienced sand loss after the 2001 survey. Cell 8 line CMP45 shows sand loss from the berm area (Figure 41a) while profile line CMP46 (more to the west) shows sand gain on the berm (Figure 41b). The volume of sand appears to be shifting from the eastern end to the western end of the cell. A net gain of about 2.5 to 5 cu m/m (1 to 2 cu yd/ft) was experienced since July 2000.

The change in cumulative volume within each of the eight cells is shown in Figure 42. The July 2000 profiles were used as baseline data and the volume change was calculated in BMAP. The profile survey for each date was compared with the July 2000 survey. Volume was measured from the start point to the end point on each profile as listed in Table 4. The pattern shows a general loss of volume in cell 1, a gain in cells 2-5 and a mix of loss and gain in cells 6-8 from July 2000 to October 2003. Cell 5 (Section 227 Beachsaver Reef installation) measured the largest gain in volume of the eight cells, with an average gain of 51.3 cu m/m (20.44 cu yd/ft) as of October 2003. The two 1994 Beachsaver Reef cells 2 and 3 also showed a gain in sand volume of around 17.6 to 20 cu m/m (7 to 8 cu yd/ft). In contrast, cell 6 (the Double-T sill installation) had an average cell volume gain of approximately 10.94 cu m/m (4.36 cu yd/ft), which was about the same as the control cell 4 at 11.14 cu m/m (4.44 cu yd/ft). The control cell 7 was the only cell with a cumulative average loss of -24 cu m/m (-9.52 cu yd/ft) of sand in the cell. Little change in volume was measured in cell 1 and cell 8, with an average gain in sand volume of only 6 cu m/m (2.46 cu-yd/ft) and 3.3 cu m/m (1.31 cu yd/ft) respectively.

Settlement and Scour Analysis

The elevation of the top of the Beachsaver Reef was measured at the crest of the unit and the top of the Double-T sill was measured on top of the seaward vertical leg (Figure 43a, b). Settlement occurred within the first 3 months following installation of other prefabricated reef projects (Stauble and Tabar 2003). This project experienced similar settlement with most settlement occurring within 6 months. Scour at the base of the units was also monitored by surveying the seaward and landward base of the units to document scour trough formation or individual unit realignment.

As each Beachsaver unit was placed, detailed measurements of elevations were made of the tops of the units and its orientation. A postconstruction survey was obtained for both the Beachsaver Reef and Double-T sill unit crests on 7 October 2002 after final placement of the last Double-T unit. Since the Double-T sill only required 4 days for installation (26 September and 2 October 2002), only one survey of the crest of these units was done on 7 October 2002. Figure 43a shows the change in elevation of the top of the Beachsaver Reef units from when each unit was placed (diamond shaped blue points on profile A-A′) and on 7 October (red upper solid line on both profile A-A′ and B-B′), 12 days after final installation. Average settlement was 0.2 m (0.7 ft) and average crest elevation was within the design range of 0.9 to 1.2 m (3 to 4 ft). Three of the Beachsaver Reef units settled into a suspected scour hole with a loss of 1.2 m (4 ft) of elevation. Most of the Double-T sill unit crests were placed to between 1.8 and 2.1 m (6 and 7 ft) depth as designed.

Subsequent settlement surveys were obtained in 2003 on 14 April (6-month), 25 July (9-month), and 24 October (Beachsaver Reef units only) and 4 November (Double-T sill units only) (12-month). On the April survey (lower blue line), the Beachsaver Reef showed more settlement near the three units that had settled earlier as well as along a section in the center of the line. As of July, the pattern was the same indicating that most of the settlement occurred in the first 6 months (lower green line). This settlement of about 1.22 m (4 ft) occurred in the area that was filled with sediment before the filter apron and units were placed during installation, approximately 91 m (300 ft) long. The eastern end experienced less settlement (0 to 0.61 m or 0 to 2 ft). This portion rested on the bottom that was excavated. The October survey (magenta lower line) shows settlement progressing to the east over time with most units reaching an equilibrium settlement depth in the center of the line. All units have shown some settlement. The units on the east end, where the bed was excavated for installation, settled the least. Only the end units remain at placement depth because they tie into the groin ends with rock (Figure 44).

The Double-T units, placed without filter cloth, settled on average 0.61 to 1.22 m (2 to 4 ft) by the April 2003 survey (lower dark line in Figure 43b). The gap in the line is where the units, already buried, could not be measured directly. As of July 2003 (green line in middle), sand covered these units and the settlement survey measured the sand surface along the line of placement. Only the structures near the west end were exposed. The rest were covered by 0.61 to 0.91 m (2 to 3 ft) of sand.

Sediment Characteristics

Sediment samples were collected on selected profile lines from each cell to get a representative sampling of the sediment distributions found before the structures were placed and to compare with the sediment distributions after the structures were installed. This sediment data will provide information to examine if the structures affect the grain-size distribution of the native beach or eventually have an effect on any beach-fill material placed on the beach. Any change in grain-size distribution may affect fill behavior or longevity.

Two sediment samples were collected from the general midtide area in cells 5 and 6 in April 2002 to characterize a winter beach condition. Grain-size analyses of the two midtide samples indicate a coarse, poorly sorted, sand with fine gravel. These samples represent a coarse lag from winter storms. Thirty-nine samples were collected in August 2002 to represent the immediate preinstallation native beach. Theses samples were more of a well-sorted, fine sand characteristic of a fair weather deposit. Three samples were collected from each selected profile at high tide (HT), midtide (MT) and in the nearshore just seaward of the low tide area (NS). Sediment samples were collected along a single middle profile line in all cells except for cells 5 and 6 (Section 227 Beachsaver Reef and Double-T sill) where all four profile lines were sampled. Further information on the sediment samples can be found in Appendix A.

Postinstallation sediments included 65 samples that were collected in July 2003 along the same profile lines. This expanded set of five samples per line include locations at HT, MT, low tide (LT), NS, and offshore (OS) which were seaward of the structures and just seaward of the groins. Due to the nature of the stone and wooden groin construction, each cell is, for the most part, separated from the next as far as sediment distributions are concerned.

No samples were collected in cell 1 since there was no dry beach except at extreme low-tide levels. A large stone revetment was located on the landward side of this cell and no dune sediment was available to be added to this cell. The large trough just offshore of this cell also limited sediment exchange within the cell.

A plot of the mean vs. sorting distribution of both the pre- and postinstallation sediments shows a trend from coarse more poorly sorted sands to finer more well sorted sands. The coarser, more poorly sorted sands were from the winter sample set in April 2002 and the preinstallation summer set (August 2002) on the western end of the study in cells 6 (CMP 36-39), 7 (CMP 42), and 8 (CMP 45) and the finer more-well sorted sands are in the eastern cell locations (cells 2-5) (Figure 45). The preinstallation samples have been identified by their location on the profile. The grouping shows that the high-tide samples are composed of medium sand size means and are more well sorted than the coarser midtide samples and the nearshore samples, which are the finest and most well sorted.

The postinstallation distribution has a wider range of mean grain sizes, but the general trend of coarser, more-poorly sorted samples on the western end of the study area remains (Figure 46). A general trend of coarser material on the

berm and midtide, with the finer material in the nearshore and offshore was also found on the postinstallation sample set, but the larger number of samples and similar means and sorting prevented a clean distinction of samples by location on the profile. The coarser and more poorly sorted samples were found at cells 7 (CMP 42) and 8 (CMP 45). In general, the MT and LT samples are more poorly sorted and coarser, while the NS and OS samples are finer and better sorted. The somewhat anomalous offshore samples being coarser and more poorly sorted in some of the cells, particularly cells 7 and 8 may be due to the wave current interaction seaward of the groins winnowing out the finer sizes. The more protected environment of the nearshore (particularly behind the three Beachsaver Reefs) may account for the deposition of the fine, well sorted sands in the nearshore.

Wave Transmission

Four pressure wave gages obtained data during the July 2003 survey period. Three gages were placed on the landward side of the Beachsaver Reef, Double-T sill and in a comparable position in cell 4. The fourth gage was placed offshore of cell 5 in 6.4 m (21 ft) of water to measure waves before they reached the structures.

It was suspected that there would be no wave attenuation in the control cell since there was no structure present. Also, the Double-T sill was too low in the water column to affect wave transmission in cell 6. Wave transmission over the Beachsaver Reef was expected to be realized since the tops of the units were designed to be at the surface during low water.

To determine the effectiveness of the Beachsaver Reef in reducing wave height, wave data were analyzed from the two wave gages on the landward and seaward sides of the submerged breakwater structure. Wave transmission coefficients were given as:

$$K_T = \frac{H_{s\ nearshore}}{H_{s\ offshore}} \tag{1}$$

where, K_T is the transmission coefficient, $H_{s\ nearshore}$ is the nearshore significant wave height measured at the respective nearshore gage, and $H_{s\ offshore}$ is the offshore significant wave height at the location of the offshore gage.

The average K_T value for the control cell area was 0.99 indicating that there was no wave attenuation in the cell without a structure (Figure 47). Wave transmission coefficients of 0.88 and 0.82 were calculated for cell 5 (Beachsaver Reef) and cell 6 (Double-T sill), respectively. The wave attenuation for the Beachsaver Reef is similar to other narrow-crested submerged breakwater installation measurement which average around 0.9 (Stauble and Tabar 2003). A bit surprising was the slightly better wave attenuation measured over the Double-T sill, which was submerged in the bed at the time. A possible explanation for this could be the shallow bathymetry and shoal off cell 6 that caused the waves to attenuate as they entered this cell. The cell was also further west and wave

approach angles from the southeast could have caused more wave refraction and attenuation by the time the waves entered the cell. From past studies, wave attenuation was not an important component of these types of structures.

Tidal Currents

Flow during ebb and flood tides is important in how sediment moves in this system. Ebb-tidal currents were measured three times on 15 July 2003, from 1100 through 1500 Eastern Standard Time (EST), as shown in Figure 24. The six lines took about an hour to complete and were repeated three times. This covered most of the ebb cycle including maximum ebb, predicted to be near the end of the ebb at 1327. A flood-tidal current survey was done on 17 July 2003, from 0800 through 1100 EST. The six lines were also repeated three times, except for the last run where line 6 was omitted due to near-slack water conditions. This survey covered the latter part of the flood cycle from about midtide to high water. Maximum flood current was predicted to be at 0813 near the beginning of the flood current data collection.

The data were processed using the starting and ending points of each transect line to spatially reference each velocity profile. The spatially referenced data were then imported into HYPAS (Hydraulic Processes Analysis System (Pratt and Cook 2001) software inside ArcView. The data were depth-averaged to produce plots of velocity magnitude and direction in vector format. Velocity vectors ranged from 0 to 2.1 m/sec (0 to 6.8 ft/sec) for both ebb and flood flows. Table 5 summarizes the physical parameters for each transect.

The ADCP plots show the transects perpendicular to the beach (lines 1 through 5) that followed the profile survey lines showed a pattern of flow in the ebb direction following the curve in the coast from the bay to the ocean (Figures 48-50). Flood flows follow the curve in the coastline into the Bay (Figures 51-53). The currents seaward of the groin tips are closely linked to the tidal flow. Sand transported off the beach is immediately carried by the flood or ebb flow. Sediment transport is either into the bay on flood tide or into the ocean on ebb. Line 6 (parallel to the shoreline) shows a complex current pattern. The boat track was just off the groin tips in the cells that have submerged breakwater (cells 2, 3, and 5) and show that the three Beachsaver Reefs deflect the flow along the seaward side of the structure. Flow inside these cells could not be measured due to the shallow clearance over the breakwaters. Visual observation of the two open cells and the submerged sill (cells 4, 7, and 6, respectively) show a complex flow indicative of circular flow into and out of the cells. Since the Double-T sill quickly sunk into the bed, this cell acted as an open cell also. During ebb flow on 15 July 2003, the general flow pattern appears to be strongest in an offshore direction along the sides of the cells and in the center the flow is generally into the cell. During flood flow, the circulation pattern appears to be generally into the cells on the bay side of the cell and out of the cell on the east side based on visual observations of floating vegetation and debris. The flood pattern appears to be a single gyre as opposed to a double gyre during the ebb flow (Figure 54).

Table 5
ADCP Data

Date and Tide Stage	Line No.	Time (EST)	Average Velocity (ft/sec)	Velocity Direction N deg E
7/15/03 Ebb	1	1127	3.4	173
		1239	3.9	172
		1356	3.1	171
	2	1138	3.7	150
		1249	4.2	151
		1406	3.0	153
	3	1149	3.8	146
		1300	4.0	145
		1417	2.7	144
	4	1159	2.4	113
		1310	2.6	116
		1427	1.6	113
	5	1208	2.7	106
		1321	2.8	101
		1438	1.4	104
	6	1219	1.1	169
		1334	1.2	174
		1453	0.5	185
7/17/03 Flood	1	0755	2.2	338
		0915	1.8	339
		1036	0.7	265
	2	0806	3.5	331
		0927	2.7	325
		1048	0.9	297
	3	0814	3.9	308
		0937	3.1	309
		1056	0.4	245
	4	0828	3.5	298
		0942	2.5	291
		1107	0.3	289
	5	0840	2.7	286
		1002	2.0	285
		1119	0.4	250
	6	0900	2.5	318
		1014	0.9	267
		Slack water – no data collected		

Aerial Photography

Color aerial orthophotos were taken in May 2002, October 2002, and October 2003. Each set is georeferenced to NAD83 horizontal datum, New Jersey State Plane coordinate system. Oblique aerials were taken on 17 September 2003 prior to Hurricane Isabel, and on 3 March 2004 during construction of the beach

fill in cell 4. The photo mosaics were used as background for the GIS analysis. The vertical photographs were used to plot a visible high-tide line and compare well with the mhw shoreline plotted from the beach profiles. Observation of wave refraction patterns both inside and outside of the cells during various wave approach directions were also observed in the photographs.

4 Discussion

Performance Criteria

The purpose of the Cape May Point Section 227 Demonstration Project is to assess the relative performance of the Beachsaver Reef and the submerged Double-T sill relative to nonstructured control areas. Three types of criteria have been chosen to evaluate performance:

a. Functional performance, the ability of the structures to retain sand within the groin compartment.

b. Economic performance, the ability to reduce the nourishment quantities and to extend the time between renourishments.

c. Structural performance, the ability of the structures to remain in a stable position over time (Stauble and Giovannozzi 2003).

Functional (Sand Retention)

Functional performance focuses on how well the structures retain sand and reduce sand loss from the cells. Losses may occur due to cross-shore processes such as postconstruction equilibration, seasonal beach profile change, and storm-induced beach erosion and due to longshore processes such as natural gradients in longshore sand transport, and interruption of sand transport by structures. Functional performance measures have been evaluated following each beach profile survey. Performance is evaluated over both incremental (survey to survey) and cumulative time scales.

Parameters

Volume change. The loss or gain of volume measured over time between the landward point of profile closure, located at the top of the dune and the offshore structure location (or seaward end of groin in the control cells). This has been determined from beach profile surveys.

After 1 year, the Beachsaver Reef in cell 5 is performing well. This cell contains more sand volume than any of the other cells relative to the preinstallation

conditions of July 2000. Sand began accumulating in December 2000 after the beach fill was placed in cells 3 and 4 (Figure 55). Sand has been transported on the beach face at the landward end of the groin between cells 4 and 5. This sand has been retained in cell 5 by the Beachsaver structure. After installation, the sand volume increased. The new installation of the Beachsaver Reef has been very successful in trapping just over 11,469 cu m (15,000 cu yd). It is acting as a perched beach, preventing sand from leaving the seaward end of the cell. Cells 2 and 3, the 1994 Beachsaver Reef installations, contain the next largest volume of sand within their respective compartments. While much less than cell 5, there is approximately 3,441 cu m (4,500 cu yd) of sand gained in these cells during this first year.

The Double-T sill cell 6 initially lost sand after installation, but has shown a steady increase in volume of sand even though the units have settled into the bed. Volume in cell 6 is about equal to the volume in cell 4 of about 3,058 cu m (4,000 cu yd). The other cells have shown a gain in volume between the July 2000 and October 2003 survey. The one exception is cell 7, the bayside control cell, which lost 4,588 cu m (6,000 cu yd) in July 2000. Cells 1 and 8 on the ocean and bay sides of the study area, respectively, experienced the least amount of accretion, about 382 to 765 cu m (500 to 1,000 cu yd).

Change in dry beach width. The dry beach width is determined from beach profile surveys based on the closest NOAA tidal station in Cape May Canal at the mouth of Delaware Bay, 3.8 km (2.4 miles) north of the site. This mhw elevation of 0.61 m (1.99 ft) NAVD was measured off each profile line. Measurement of the wet/dry line off of the aerial photography was also done to supplement this analysis.

The shoreline has advanced seaward the most relative to the July 2000 shoreline position in cell 3 (the original 1994 Beachsaver Reef) and cell 5 (the Section 227 2002 Beachsaver Reef). Cell 3 received sand nourishment in January 2001. Cell 2 (the other 1994 Beachsaver Reef deployment) had the next most seaward movement of the mhw line, followed closely by control cell 4, which also received sand nourishment in January 2001 (Figure 56).

The shoreline has retreated from the July 2000 mhw shoreline position in cells 7 and 8 (the two western control cells). The greatest retreat was measured in cell 6, which contains the Double-T sill structure.

Functional performance measures

A1. Difference in net volume change between structured and nonstructured groin cells.

Evaluation Criterion: Structure is successful in retaining sand if reduction in volume loss is 30 percent or more in comparison to nonstructured cell for annual base volume losses <5 cu m/m (<2 cu yd/ft).

The 227 Beachsaver Reef cell, on average, has retained the most sand of the eight cells. Comparing the average volume change in cell 4 with cell 5 indicates

that the criterion of reduction in volume loss of more than 30 percent has been met. The Double-T sill (cell 6) average volume retention compared with cell 4 over the first year, indicates that the Double-T sill did not meet this criterion.

A2. Difference in net volume change between cells with Beachsaver Reef and Double-T submerged sill.

Evaluation Criterion: Structure outperforms competing design if relative reduction in volume loss is 30 percent or more for annual base volume losses <5 cu m/m (<2 cu yd/ft).

The Double-T sill cell gained around 6.8 cu m/m (2.71 cu yd/ft) compared with a gain of 29.3 cu m/m (11.69 cu yd/ft) for the Beachsaver Reef cell. The Beachsaver Reef structure was more successful in retaining sand than the Double-T sill.

B1. Difference in dry beach width change between structured and non-structured groin cells.

Evaluation Criterion: Structure is successful in retaining dry beach width if reduction in beach width loss is 30 percent or more in comparison to non-structured cell for annual base beach width loss <0.91 m (<3 ft).

The mhw shoreline moved seaward on average 4.27 m (14 ft) behind the Beachsaver Reef and retreated on average 2.67 m (8.75 ft) behind the Double-T sill when compared with cell 4 which experienced an average shoreline retreat of 4.88 m (16 ft), based on comparing the pre- (March 2002) to post-structure placement (October 2003) shoreline. Both structures performed better than the control. (Quantitatively, the annual base beach width loss: Control cell 4 = -4.88 m/year (-16 ft/year); Beachsaver = +4.27 m/year (+14 ft/year) which is reversed from loss to gain in width; Double-T = -2.67 m/year (-8.75 ft/year) which reduced the beach width loss by 45 percent over the control. Both meet the success threshold, but the Beachsaver outperformed the Double-T sill.)

B2. Difference in dry beach width change between cells with Beachsaver Reef and Double-T sill.

Evaluation Criterion: Structure outperforms competing design if relative reduction in beach width loss is 30 percent or more for annual base beach width loss <0.91 m (<3 ft).

The Beachsaver Reef cell outperformed the Double-T sill with a shoreline advance compared to shoreline retreat for the first year.

Economic (Reduction of Renourishment Quantities/Lengthening of Renourishment Cycle)

Economic performance focuses on project cost savings realized for the Lower Cape May Meadows - Cape May Point Federal Beach Nourishment/ Environmental Restoration Project as a result of reduced renourishment quantities and/or a longer renourishment cycle. Economic performance will be evaluated after initial construction of the Federal project. The design renourishment cycle for the Federal project is 4 years. The first six cells are within the boundary of the Lower Cape May Meadows - Cape May Point Project, which is scheduled to place sand at the end of 2004. After fill placement in cells 5 and 6, it will be monitored for at least 6 months to see how well the two structures hold the fill material over time relative to the other four cells.

Since no beach fill was placed during the first year of monitoring, this criterion could not be evaluated. Economics will be evaluated after the Federal beachfill project is constructed in late 2004. Fill will be placed in the cells 1 through 6 and will be monitored for sand volume and shoreline position change at cells with the Beachsaver Reef (cells 2, 3, and 5) and the Double-T sill (cell 6) relative to the control cells (cells 4, 7, and 8). Cells 7 and 8 will not be filled but will be monitored. Renourishment requirements will be based on the design beach width and sand volume requirements of the Lower Cape May Meadows - Cape May Point Federal Beach Nourishment/Environmental Restoration Project.

Parameters

The economic analysis is based on the cost of additional sand volume needed for the first renourishment to bring the project up to design specifications in the structured cells relative to the nonstructured cells. Any extension on the time interval between initial placement and the first renourishment will also translate into a cost savings. Parameter definitions are listed in the following paragraphs.

Renourishment volume requirements: Volume of sand required to restore the beach profile to the design template plus advanced nourishment (and associated cost). The volume requirements will be determined from measurements of change in beach profile surveys of the as-built relative to subsequent surveys. Cost analysis includes renourishment sand resource needs and dredging operations.

Renourishment interval: Length of time between construction and the condition survey that measures when the beach profile volume and/or width are less than the design template. Determined from beach profile survey volume and shoreline position changes, aerial photography measurement of shoreline position change, and cost analysis of associated renourishment cycle differences between structured cells and nonstructured cells.

Economic performance measures

A1. Difference in costs to renourish structured and nonstructured groin cells (based on different volume requirements). Average annual renourishment cost savings for structured cells versus average annual cost of structure.

Evaluation Criterion: The structure will be deemed successful if the average annual renourishment cost savings exceeds the annualized structure cost.

A2. Difference between costs to renourish groin cells with Beachsaver Reef and Double-T sill. Comparison of average annual renourishment cost savings versus average annual cost of structure for Beachsaver Reef and submerged sill.

Evaluation Criterion: Structure outperforms competing design if incremental renourishment cost savings is greater than incremental structure cost.

B1. Difference in renourishment interval for structured versus non-structured cells. Average annual cost savings over 50-year project life for longer renourishment cycle of structured cell versus average annual cost of structure.

Evaluation Criterion: Structure will be deemed successful if average annual cost savings of longer renourishment cycle exceeds the annualized structure cost.

B2. Difference between renourishment interval for groin cells with Beachsaver Reef and Double-T sill. Comparison of average annual cost savings of longer renourishment cycle versus average annual cost of structure for Beachsaver Reef and Double-T sill.

Evaluation Criterion: Structure outperforms competing design if incremental cost savings of longer renourishment cycle is greater than incremental structure cost.

Structural (Structural Stability)

Structural performance measures focus on stability of the structures. The structures should maintain functionality over a design life consistent with that of a beachfill project (i.e., 50 years) while requiring minimal operation and maintenance. Structural performance is evaluated throughout the duration of the monitoring program to assess both short and long-term stability issues.

Parameters

The three parameters are as follows:

a. Change in elevation of structure crest: Decrease in elevation of structure crest due to settlement, rotation, or translation. Determined from elevation surveys along crest of structure.

b. Change in alongshore structure integrity: Formation of gaps in structure due to separation of interlocking units or other structure failure resulting in sand loss due to higher permeability. Determined from elevation surveys along structure.

c. Scour depth: Elevation of seabed adjacent to structure (seaward and landward sides) in comparison to initial elevation at time of structure placement. Excessive scour may result in failure of structure or change sand transport patterns.

Structural performance measure

The structural performance evaluation was based on the three parameters stated and was examined for the new Beachsaver Reef, and the Double-T sill. Some measure of the existing 1994 Beachsaver Reef stability was also monitored with the profile surveys, but no separate structural surveys were taken.

A1. Evaluation of settlement of the Beachsaver Reef and Double-T sill units on the bed.

Evaluation Criteria: Successful if average lowering of crest elevation is <0.31 m (<1 ft).

The new Section 227 Beachsaver Reef has settled differentially across the cell with maximum settlement along its western end of 1.22 m (4 ft). The settlement of some individual units was greater than 0.31 m (1 ft). Settlement occurred within a few weeks on a few units and progressed to the western half of the structure by the end of the first year. Some of the eastern end units also settled to varying degrees, but less than the western end. Excavation of the bed for installation on the eastern end provided a more solid foundation than the fill that was required to raise the western end at placement. This fill material may not have consolidated before the filter cloth and units were placed causing settlement. Strong currents were reported by the contractor around the ends of the breakwater units as they were being placed. This may have led to foundation instabilities and subsequent settlement along the western end. Both volume and shoreline position changes indicate that settlement has not affected the ability of the submerged breakwater to retain sand and act as a perched beach.

The Double-T sill settled into the bottom and was covered with sand within the first 6 months. Settlement was also greater than 0.31 m (1 ft) along almost its entire length of the cell. The entire structure is now buried (except at the ends where it is tied into the adjacent groin) and stability cannot be determined. The volume and shoreline change analysis indicates that this settlement has prevented this breakwater from retaining sand or stabilizing the shore.

Neither structure satisfied the criteria for success in terms of settlement. However, the Beachsaver Reef appears to retain functionality despite settling greater than the 0.31-m (1-ft) criteria. The Double-T sill appears to be ineffective due to excessive settlement.

The existing Beachsaver Reef in cells 2 and 3 were not surveyed along the crest length but were monitored where the profile crossed the line of the structure. There appeared to be no settlement over this first year of Section 227 project monitoring. These units had settled within the first 6 months of initial installation in 1994 (Herrington et al. 1997) and have been stable since. The breakwaters appear to be stabilizing the shoreline and retaining sand, but not as efficiently as the new cell 5 installation.

B1. Realignment of the units and alongshore stability of breakwater structure.

Successful if no gaps form that result in localized sand loss through structure.

The settlement of the Beachsaver Reef units in the western half of the line caused a gap in the structure crest. As of the first year, the ability of the structure to retain sand is still working since the gap in the reef is still above the sand level. The settled units are still retaining sand but are lower in the water column and will allow sand to flow over the units first as the level of the sand accumulates behind the structure.

The Double-T sill structure has disappeared into the bottom and is not retaining sand, except for a small mound over the structure. The shoreline retreat and loss of sand volume in this cell indicate that the sill structure is not working as designed.

C1. Scour at the base of the units.

Successful if average scour is <0.61 m (<2ft).

The geotextile filter cloth and geotube structure have not prevented scour at the landward base of the Beachsaver Reef. A scour trough about 1.2 m (4 ft) deep exists on its landward side. Based on the profiles, the 1994 Beachsaver Reefs in cells 2 and 3, also have a scour trough on the landward side 0.91 to 1.22 m (3 to 4 ft) deep. The geotextile filter cloth beneath the Beachsaver Reef units did not prevent the scour trough from forming, or effect unit settlement, as evident from the presence of a landward trough even in the area of settlement of the western end of the structure.

No scour occurred at the Double-T sill units. They settled uniformly into the bottom before the first monitoring survey and are covered by approximately 1.22 m (4 ft) of sand. They are unable to retain sand and act as a sill feature since they are buried. They are sheltered from wave and current action and have little effect on retaining sand as evidenced by loss of sand volume and retreat of the shoreline in this cell.

5 Summary

This report summarizes the first year of monitoring after the placement of a Beachsaver Reef prefabricated concrete, narrow-crested, submerged breakwater and a Double-T sill prefabricated, submerged, concrete structure at the seaward end of two compartments in a groin field located at Cape May Point, NJ. This is the first project to be completely constructed as part of the National Shoreline Erosion Control Development and Demonstration Program, commonly referred to as Section 227. A monitoring program was established to include: profile surveys, settlement surveys, sediment samples, wave and current measurements, and aerial photography. Data analysis includes profile and shoreline change evaluation to assess the project's functional performance in retaining sand volume within the groin compartments and maintaining a stable shoreline position. This coast is in an area subject to beach and dune face erosion and landward retreat of the shoreline due to interactions between waves and currents. Structural stability was monitored to document scour, settlement, and reorientation to evaluate the benefits of use of these types of structures for shore protection projects.

Additional data collection over the next 2 years of this 3-year study will be used to determine the effectiveness of the Beachsaver Reef and Double-T sill. Functional performance of the units is being evaluated to see if these structures provide a viable way to stabilize the shoreline and hold sand in coastal areas subject to erosion by waves and currents. Economic performance will be evaluated in the third year to assess the effectiveness of these structures to retain beach fill and extend renourishment intervals. Structural performance evaluation indicates both structures have settlement problems. The geotextile fabric layer used with the Beachsaver Reef was not very effective in preventing scour and settlement. Problems encountered during installation of the Beachsaver Reef in maintaining a desired depth of placement may be responsible for settlement where fill was needed to raise the bottom to the design elevation before placement. This fill material was placed just before the geotextile underlayment and structure were placed and may not have had time to consolidate. Strong tidal currents caused scour at the end of each unit as it was placed. The most settlement correlated with the area where the fill was placed.

The Double-T sill units settled completely into the bed except for the end units. No filter cloth was put under the Double-T units. This structure settled into the bed within the first 6 months of the study. This settlement was not expected.

Settlement was measured for both structure types, but their ability to retain sand within their respective compartments was mixed. The Beachsaver Reef has

retained sand on its landward side and the nearshore profile inside the structure has been raised. Even where the reef has settled, sand accumulated on its landward side. The shoreline position has also stabilized. Sand has deposited over the Double-T units, but the gain in sand volume is limited to a small mound over the buried sill. Little sand was retained and the shoreline retreated. The functional performance of the Beachsaver Reef was better than the control cells. The Double-T sill cell performance was about the same as the control cells.

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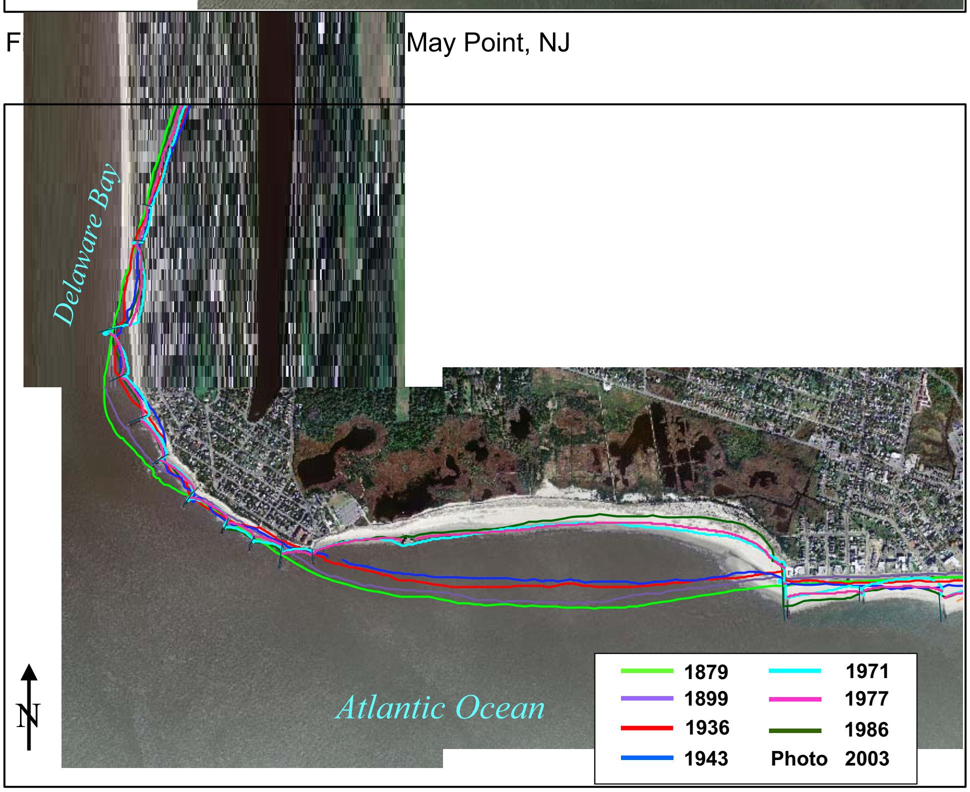
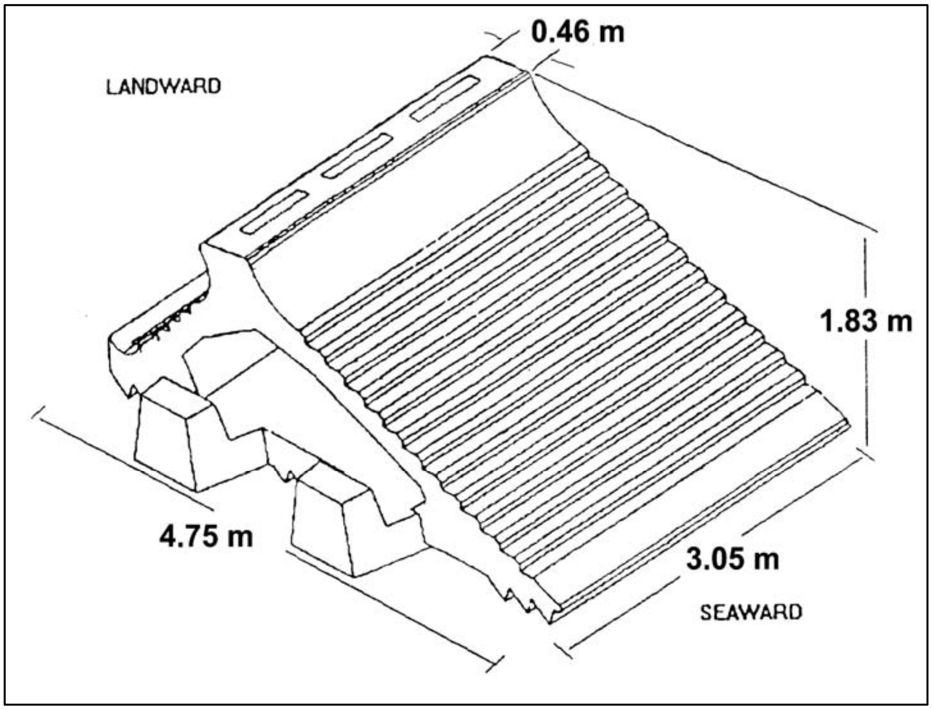


Figure 2. Historic shoreline changes at Cape May Point

Figure 3. Location and history of shore protection structures



a. Dimensions

b. End showing interlocking mechanism

Figure 4. Beachsaver Reef unit (continued)

c. Example of placement in linear installation as at Cape May Point

Figure 4. (concluded)

Figure 5. Placement of geotextile filter blanket/tube and Beachsaver Reef unit (practice run). Tube is placed on landward side

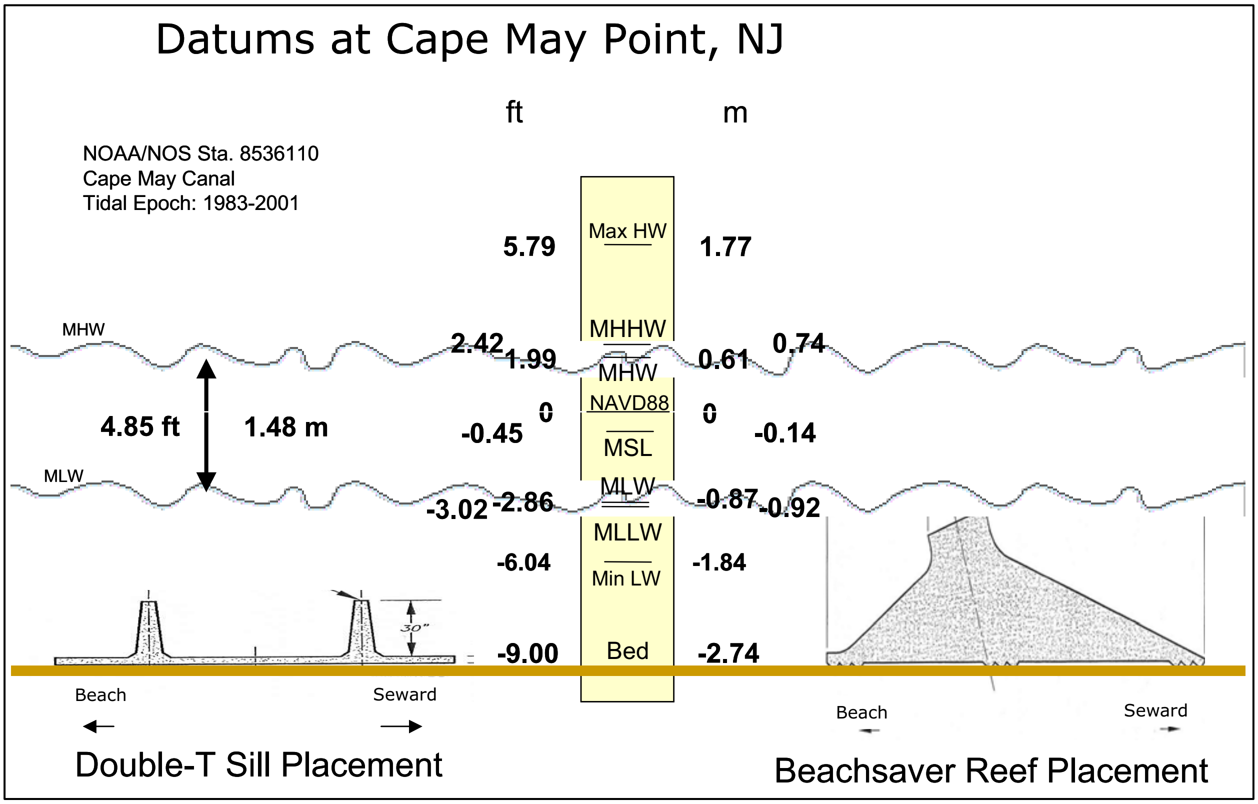
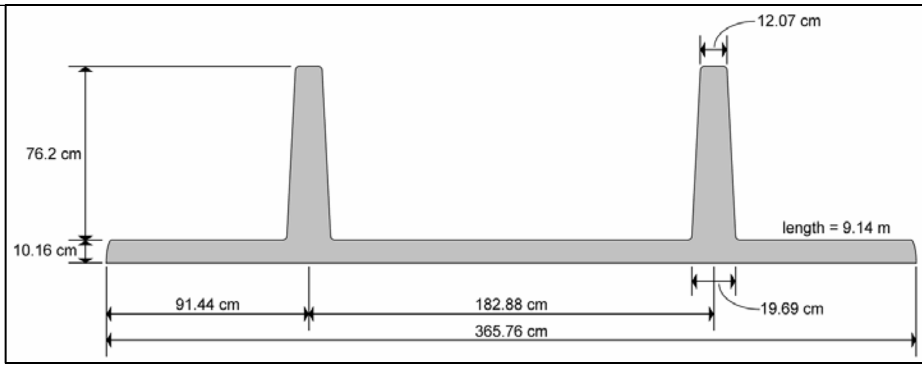


Figure 6. Datums at Cape May Point showing placement depths



a. Dimensions

b. Typical orientation as parking garage unit

c. Section 227 inverted placement position

Figure 7. Double-T Sill (continued)

d. Close-up of interlocking end

Figure 7. (concluded)

Figure 8. Geotextile blanket/tube installation in cell 5, August 2002

Figure 9. Installation of Beachsaver Reef units in cell 5, August 2002

Figure 10. Installation of rock end of both breakwater types to tie units into adjacent groin

Figure 11. Backhoe used to excavate and fill under Beachsaver Reef

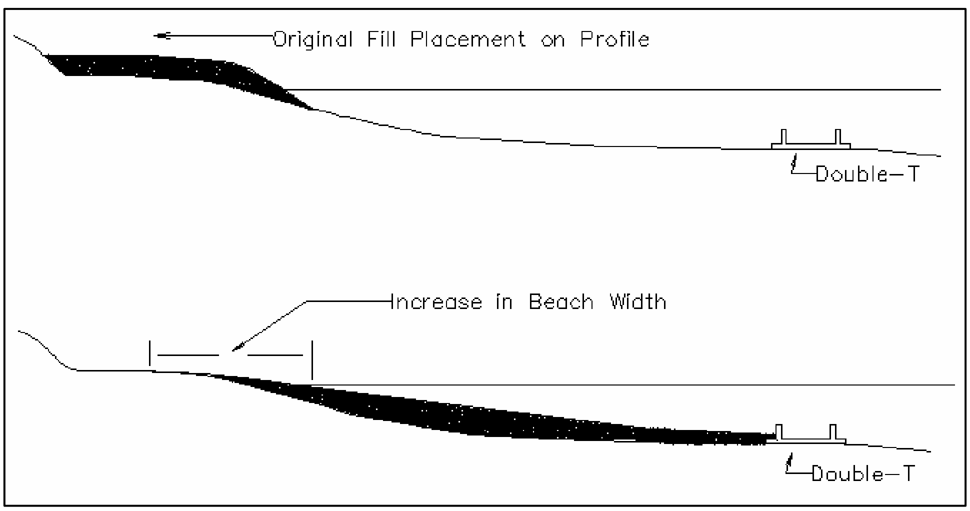


Figure 12. Expected beach response to Double-T sill

Figure 13. Installation of Double-T sill by barge mounted crane. Notice the positioning rods on suspended unit and on end of previously placed unit in water

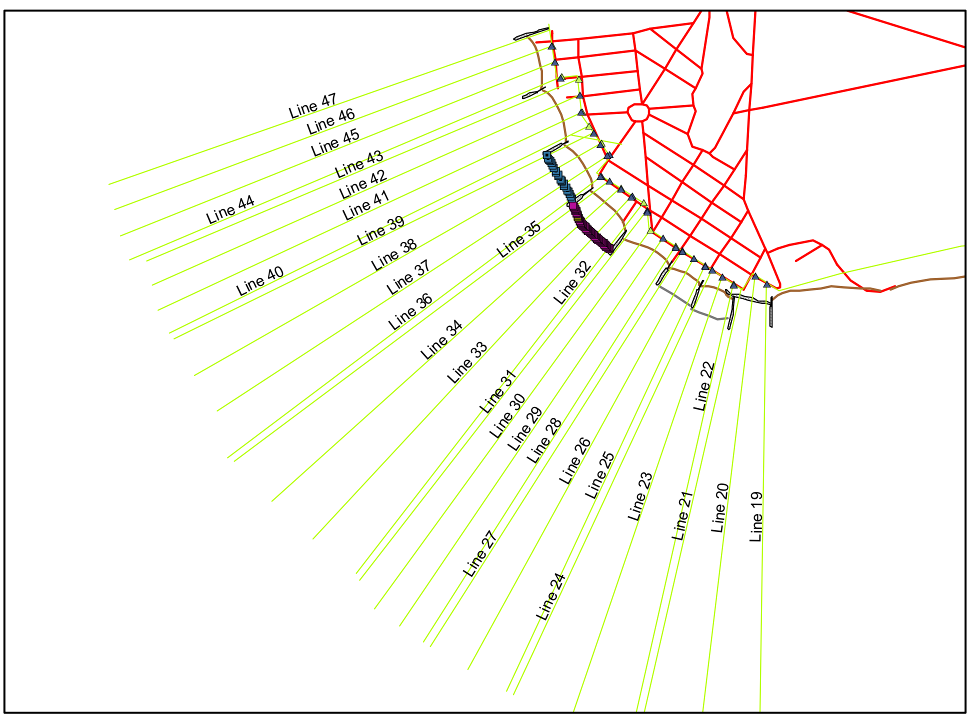


Figure 14. Location of 29 profile lines

a. Dune area using GPS

b. Beach and wading depth area using total station

Figure 15. Profile survey techniques (continued)

c. Nearshore area using boat and fathometer

Figure 15. (concluded)

Figure 16. Ice buildup on site in January 2003

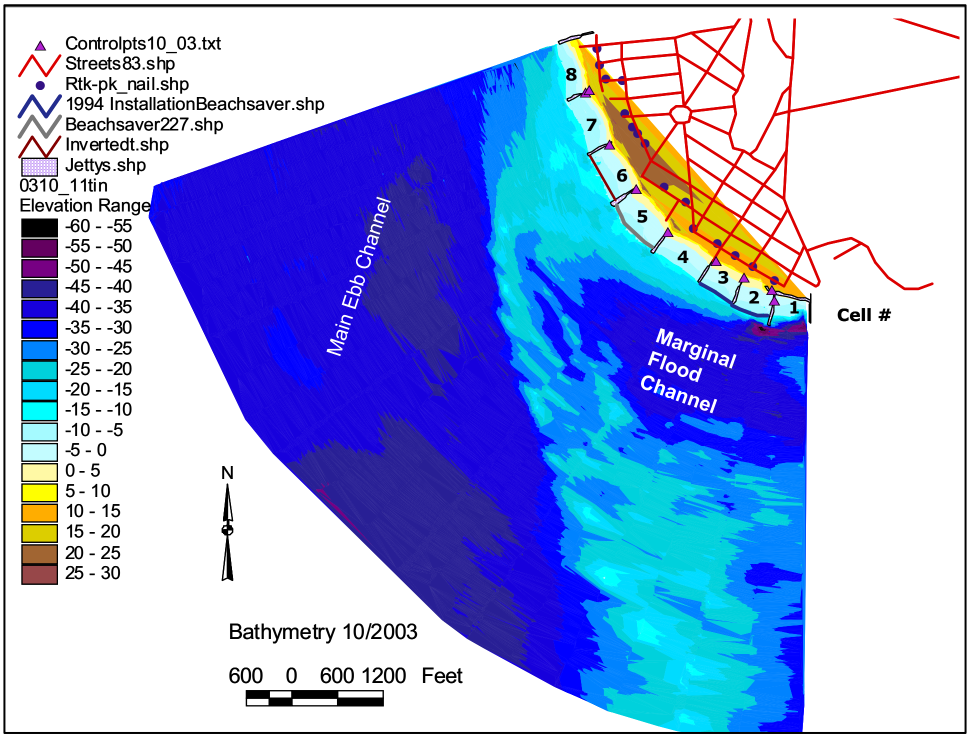


Figure 17. Example of GIS TIN bathymetry. Depth relative to NAVD88

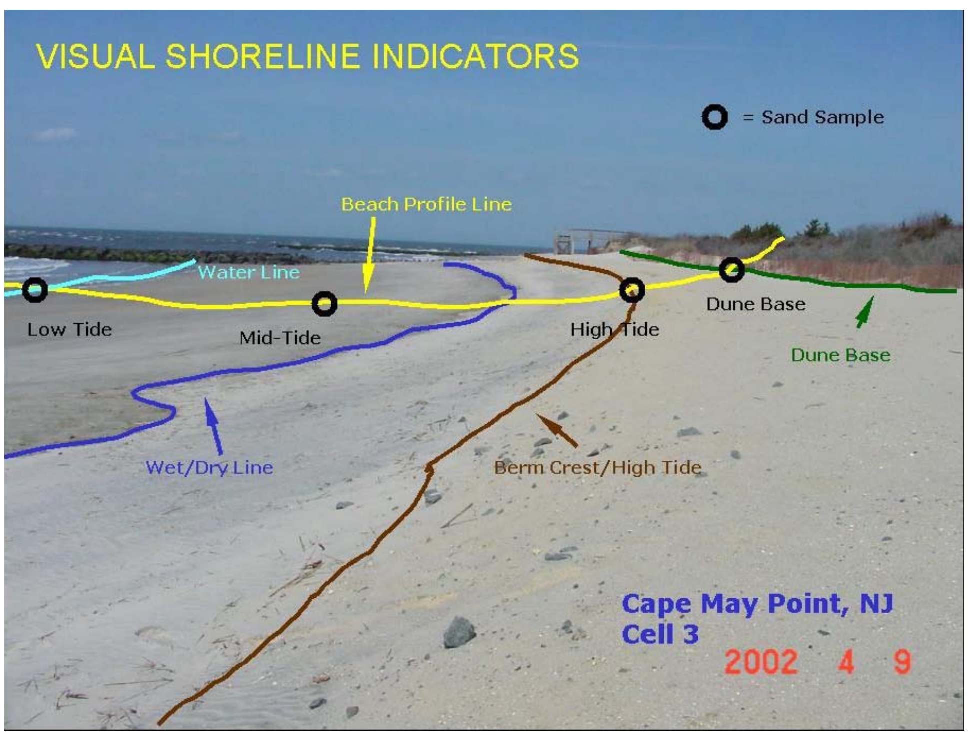


Figure 18. Example of wet/dry line and high-water line on typical area beach

Figure 19. Swimmers with survey rod standing on top of Beachsaver Reef for settlement measurements

Figure 20. Sediment sample location and collection method

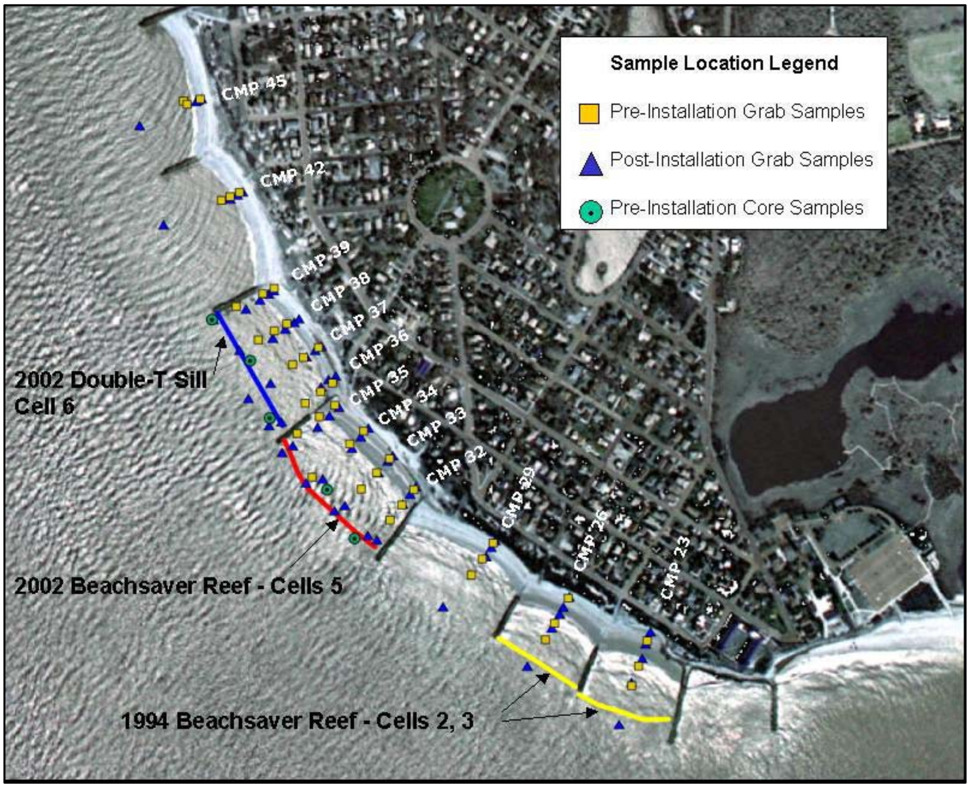


Figure 21. Location of sediment grab samples of preinstallation (8/02) and postinstallation (7/03), along with preinstallation cores (11/00 and 6/01)

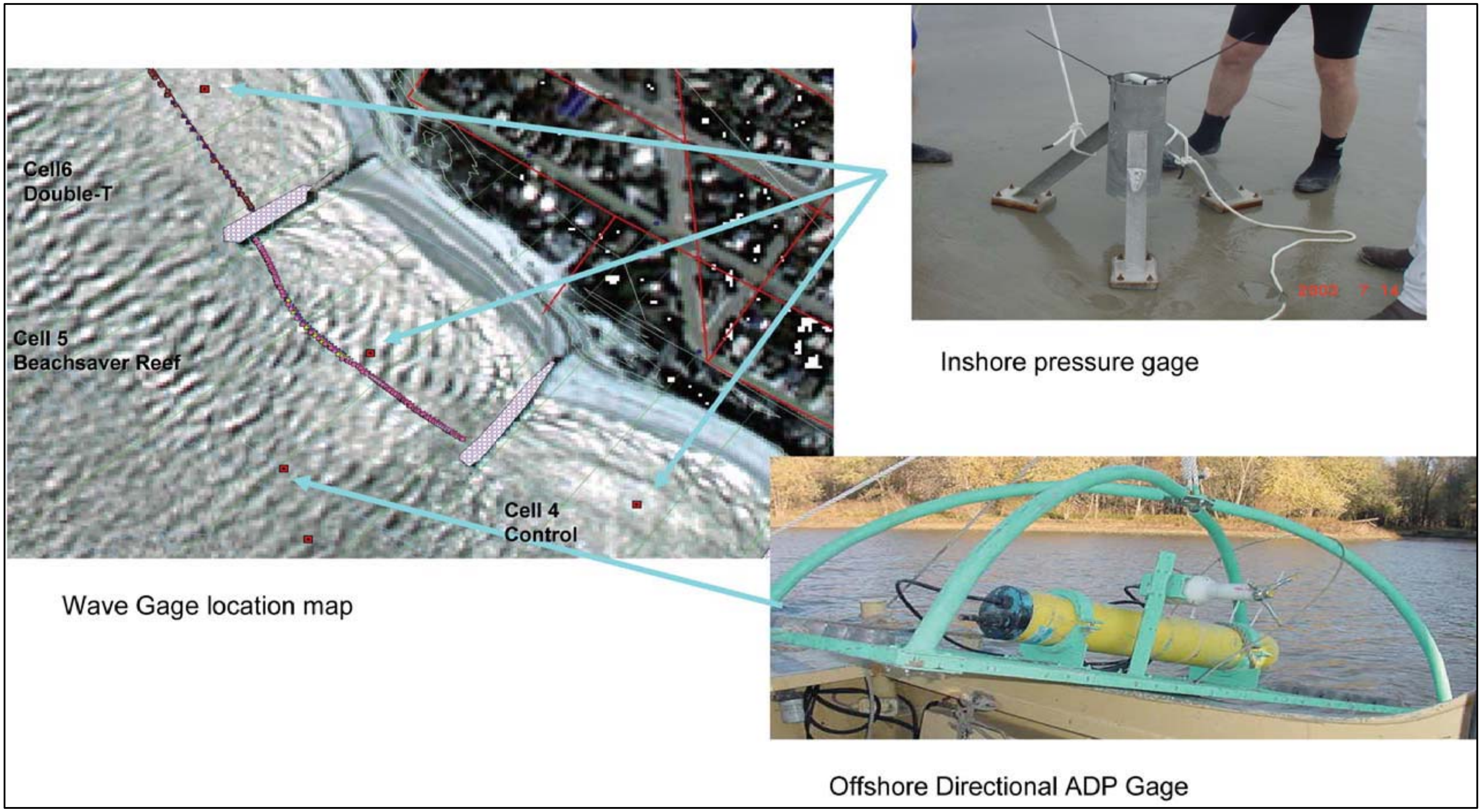


Figure 22. Location of wave gage and types of mounts used

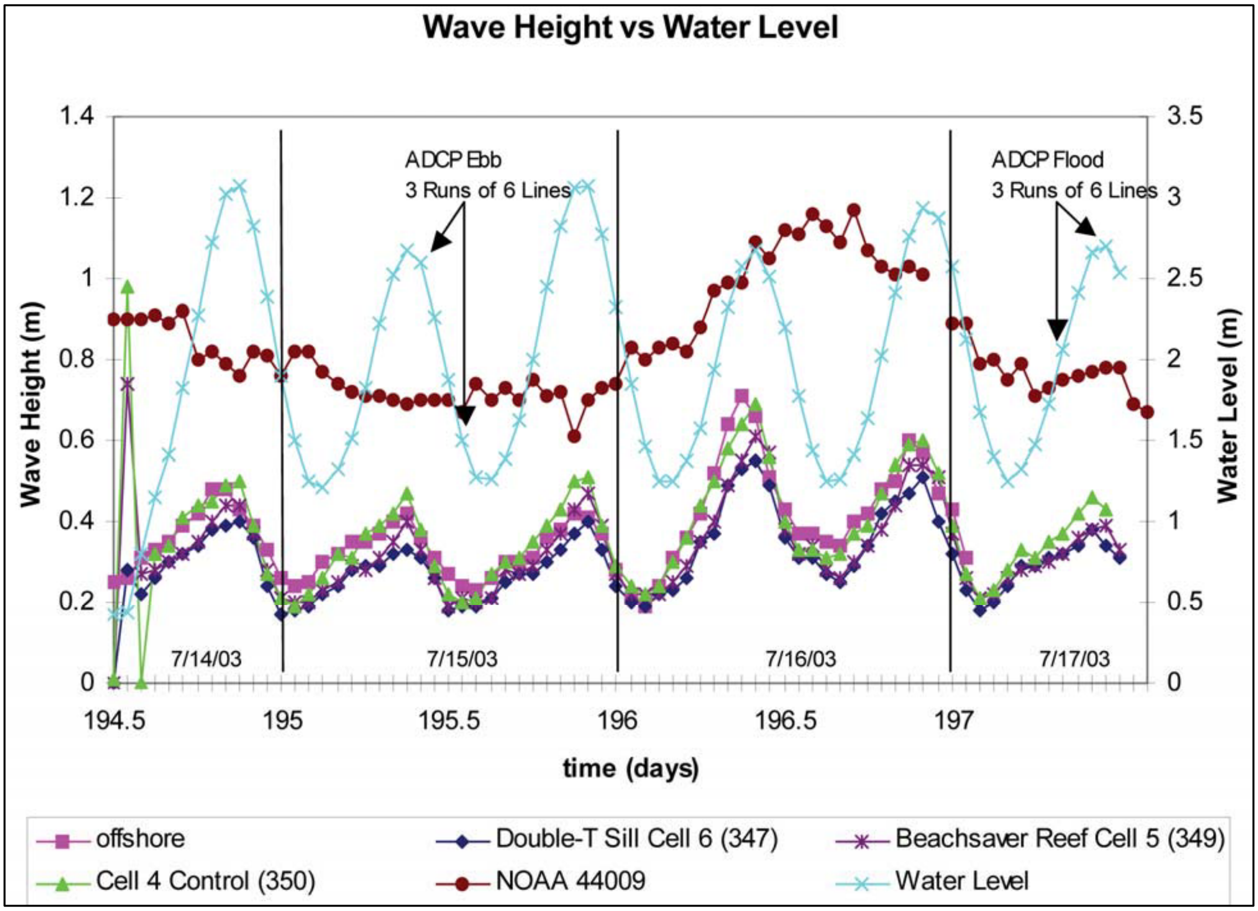


Figure 23. Time series of wave height and water level elevations from NOAA bouy and four wave gages during 60-hr data collection between 14 July (12:00 EDT) and 17 July 2003 (14:00 EDT)

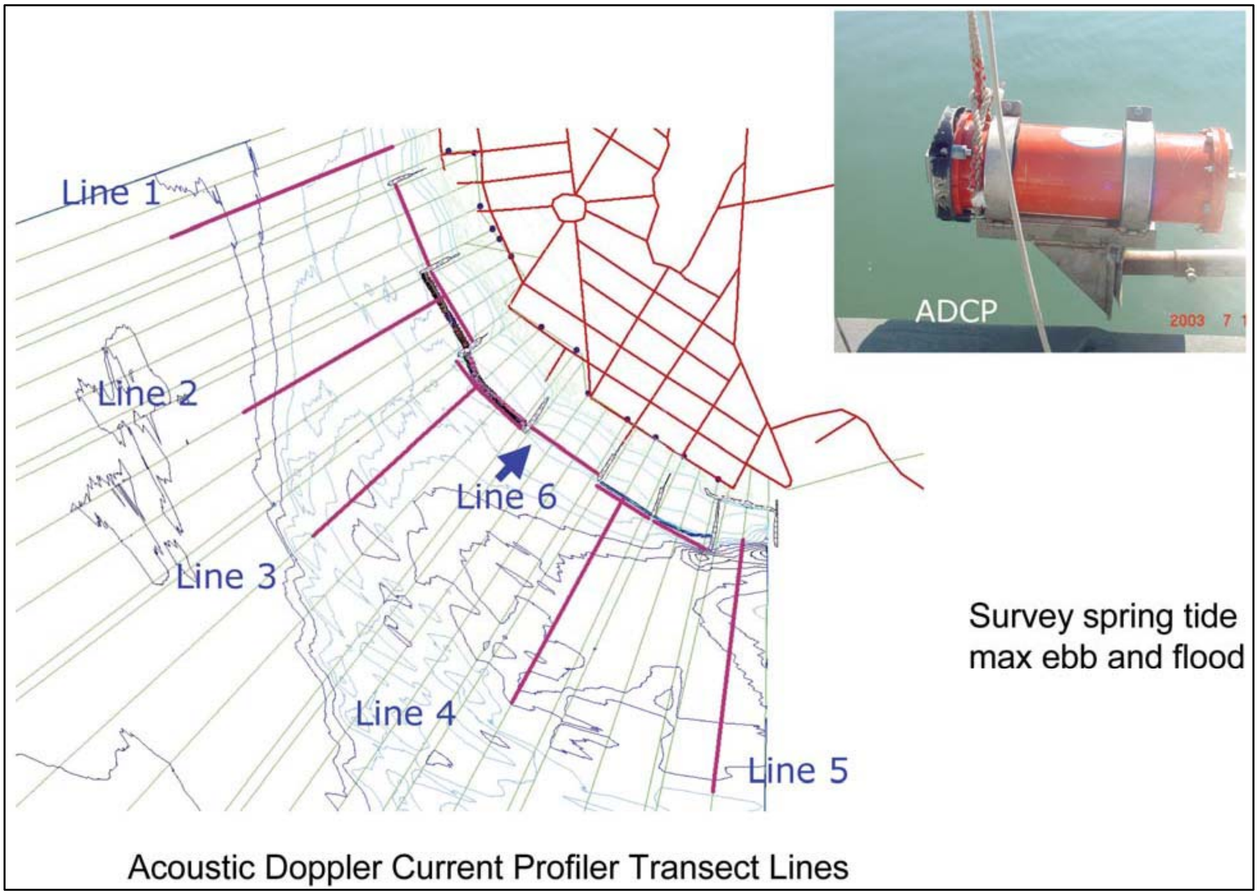


Figure 24. Location of five shore-perpendicular and one shore-parallel ADCP lines and boat mounted ADCP sensor (insert)

Figure 25. View eastward in cell 1 showing rock seawall (note absence of dry beach). Photograph taken around low tide

Figure 26. Looking eastward in cell 2 showing rock revetment and gabion seawall. A 1994 Beachsaver Reef is located in this cell

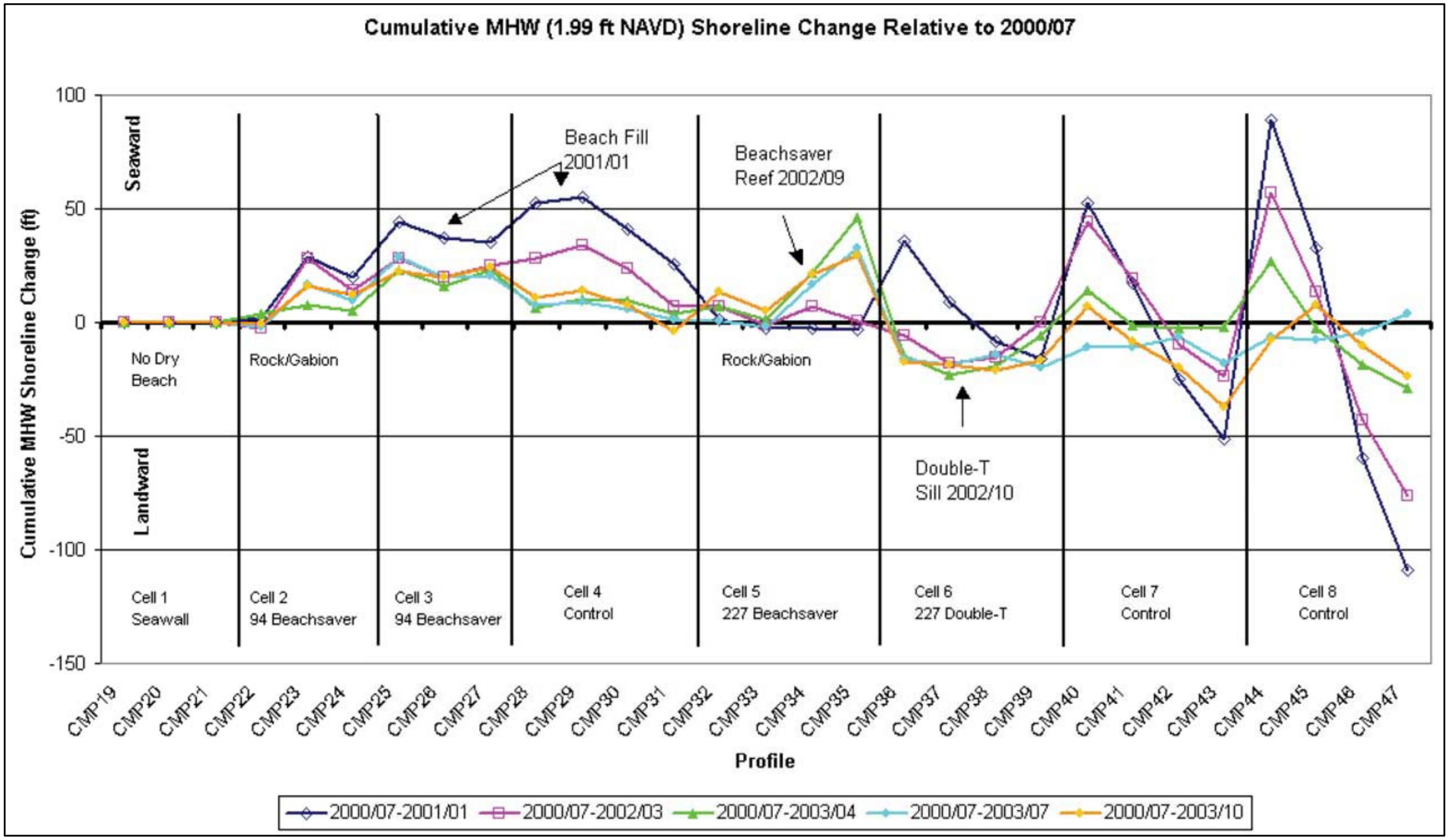


Figure 27. Cumulative mhw shoreline change on each profile line relative to July 2000

Figure 28. Looking eastward in cell 3, which is backed by a dune and was nourished in 1/2001 (second 1994 Beachsaver Reef is in this cell)

Figure 29. Looking eastward in control cell 4, which was nourished in 1/2001

Figure 30. Looking eastward in cell 5 showing gabion and rock revetment at base of dune. Section 227 Beachsaver Reef is in this cell

Figure 31. Looking eastward in cell 6 showing large amount of debris on beach, common for this cell. Section 227 Double-T Sill is in this cell

Figure 32. Looking eastward in cell 7 (western control cell)

Figure 33. Looking eastward in cell 8, westernmost groin compartment

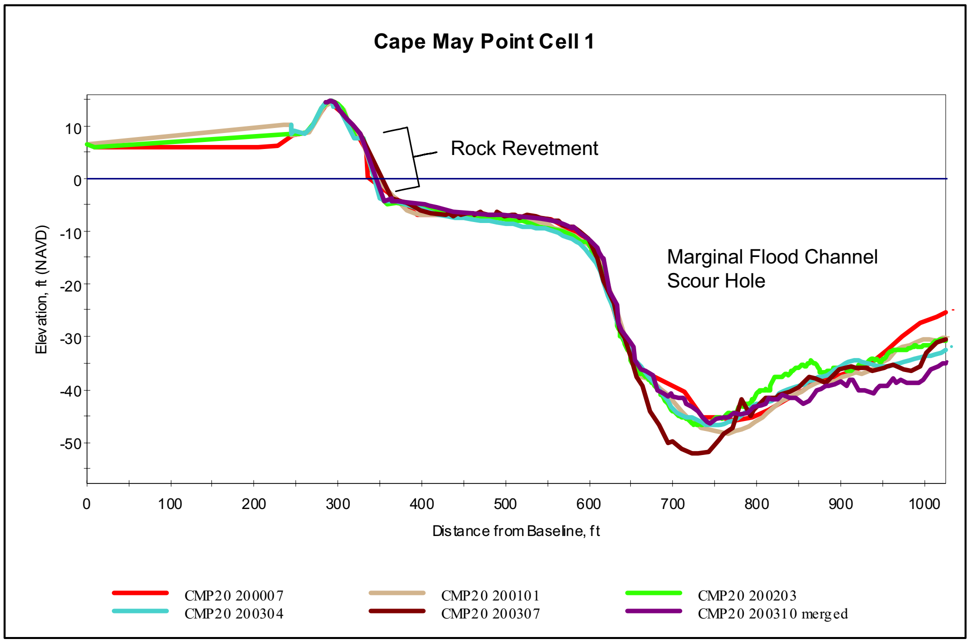


Figure 34. Cell 1 representative profile changes on line CMP20 from 7/2000 to 10/2003. Cell 1 has no dry beach and is backed by a rock seawall. Note deep trough just seaward of groin ends (around 620 ft from baseline)

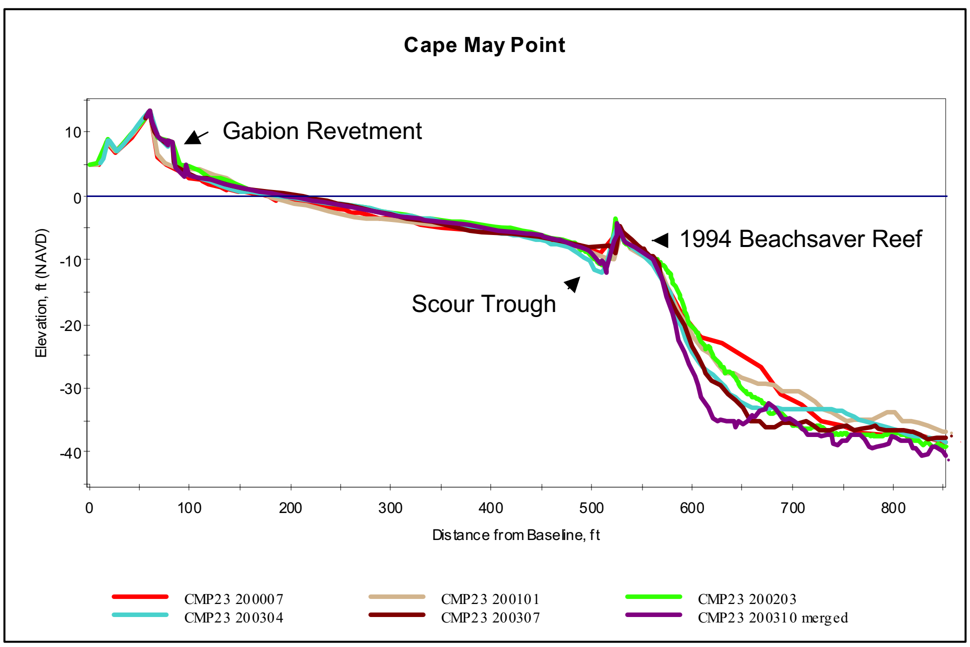


Figure 35. Cell 2 representative profile changes on line CMP23 from 7/2000 to 10/2003. Cell 2 has a 1994 Beachsaver Reef breakwater at seaward end of cell. Note scour trough just landward of breakwater. Gabion revetment is located at base of dune

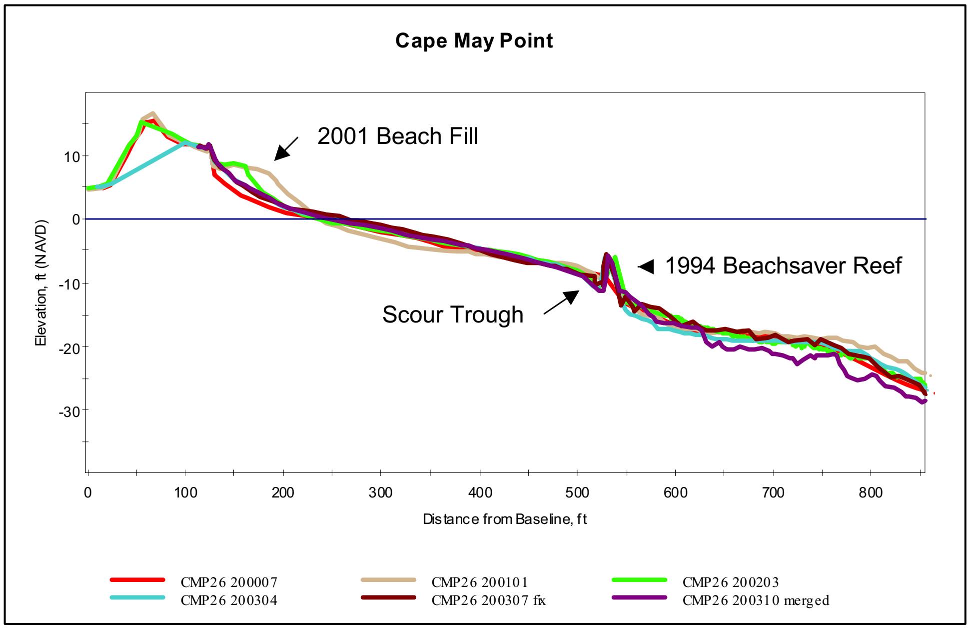


Figure 36. Cell 3 representative profile changes on line CMP26 from 7/2000 to 10/2003. Cell 3 has a 1994 Beachsaver Reef breakwater. Note scour trough. The 1/2001 beach fill can also be seen on berm area from 1/2001 to 3/2002

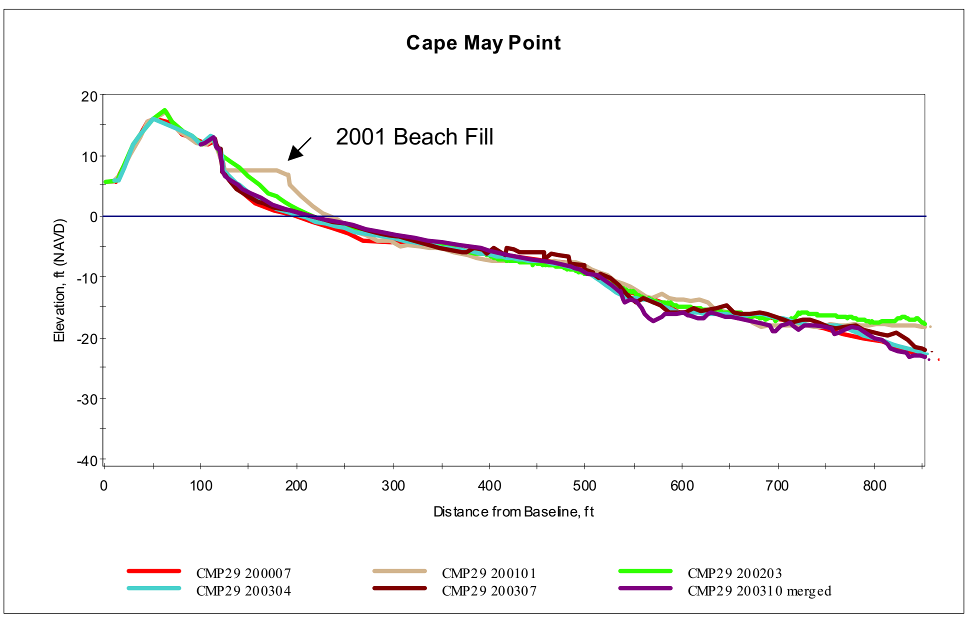
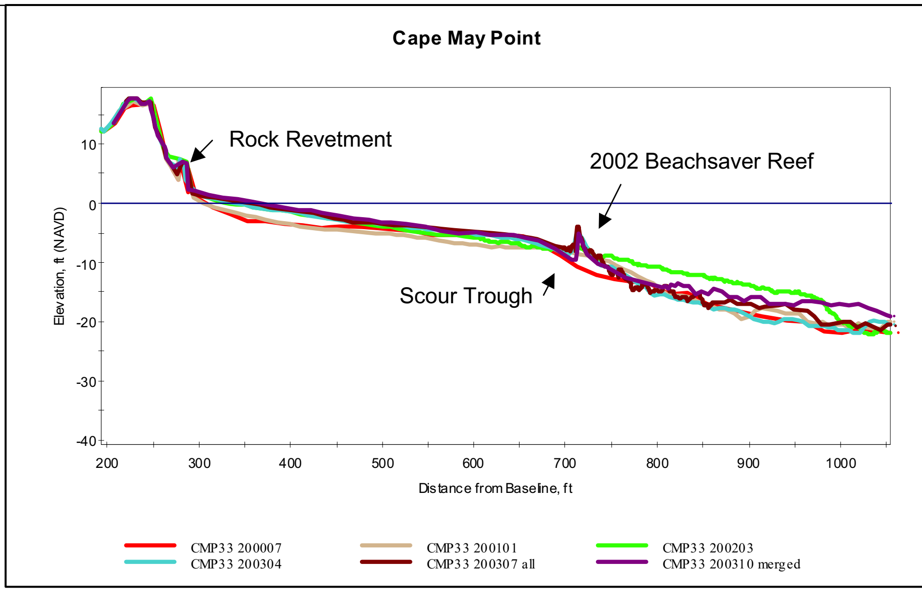
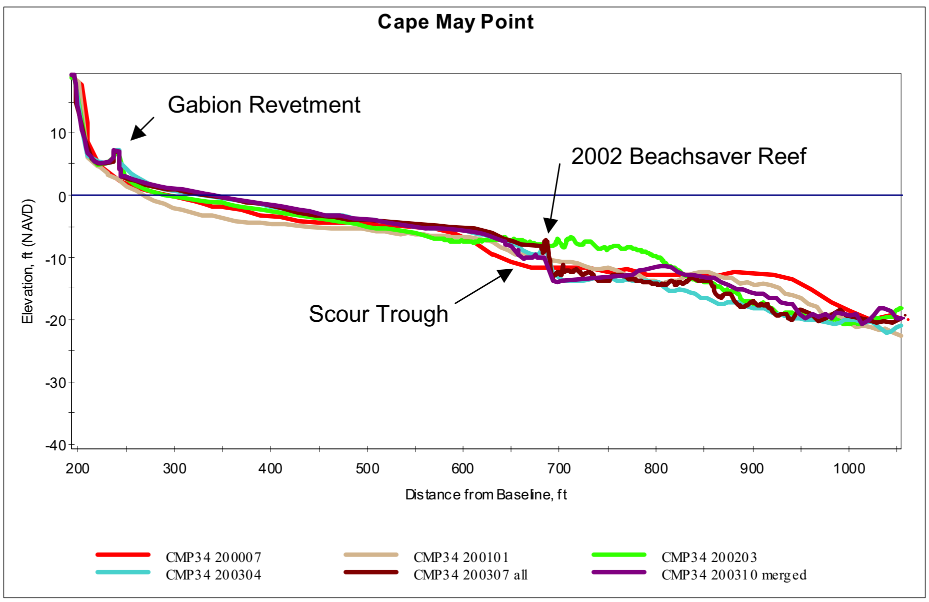


Figure 37. Cell 4 representative profile changes on line CMP29 from 7/2000 to 10/2003. Cell 4 is the control cell with no structures. Note 1/2001 beach fill on berm from 1/2001 to 3/2002

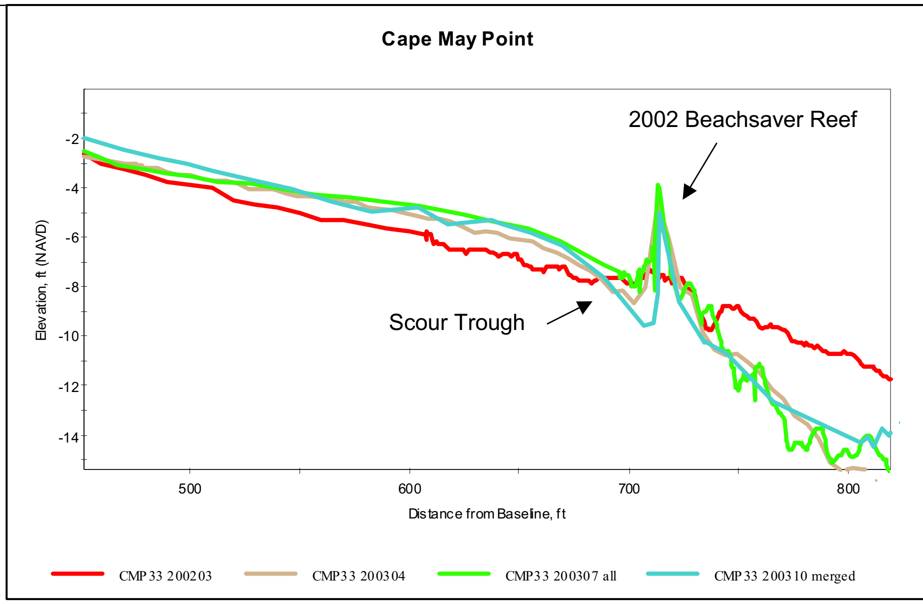


a. Line CMP33 from 7/2000 to 10/2003. Section 227 Beachsaver Reef installation shows a scour trough at landward base of breakwater. Rock and gabion revetment are at dune base. Profile is on eastern side of compartment and did not exhibit settlement of Beachsaver Reef units



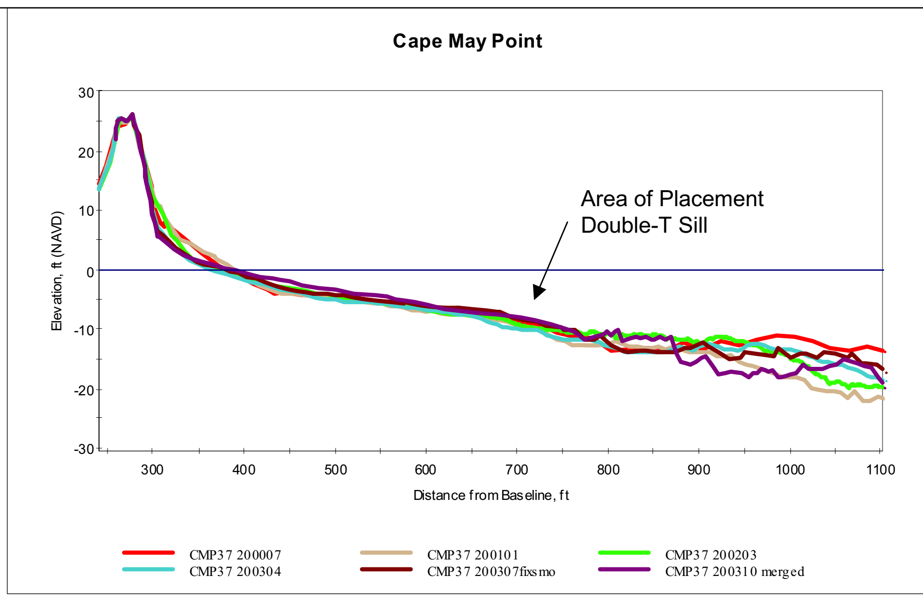
b. Line CMP34 from 7/2000 to 10/2003. This profile is on western side of compartment, where fill was required to place Section 227 Beachsaver Reef at desired depth. Breakwater units have settled on profile and top of structure is almost even with sand

Figure 38. Cell 5 representative profile changes (continued)



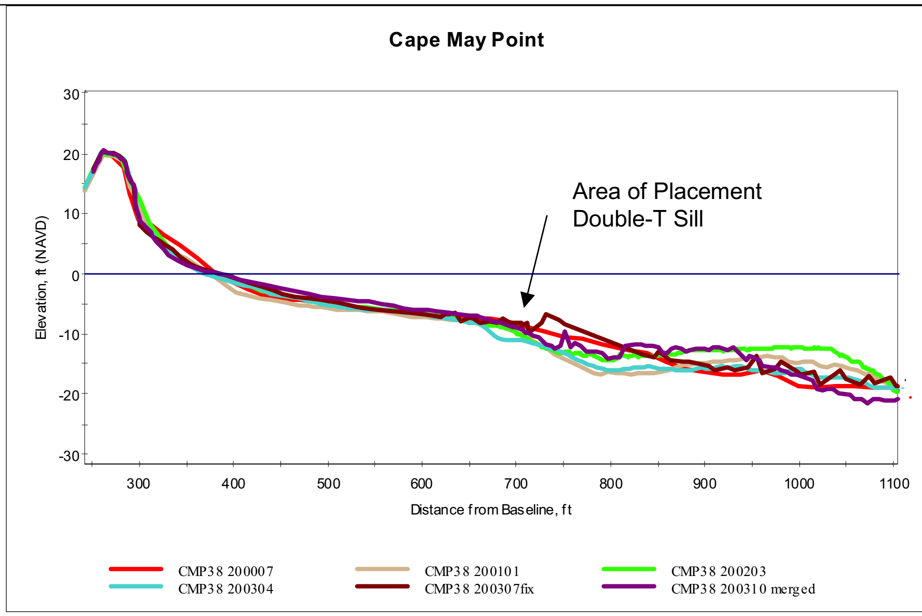
c. Close-up of profile changes on Line CMP33 in vicinity of Section 227 Beachsaver Reef showing trough on landward side of breakwater. 3/2002 is preinstallation and other three dates are postinstallation

Figure 38. (concluded)

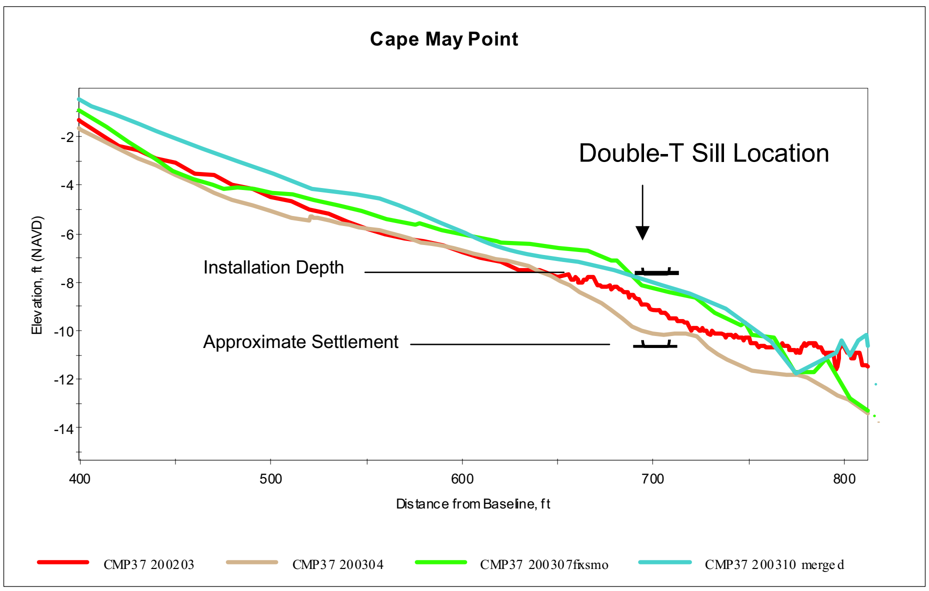


a. Line CMP37 from 7/2000 to 10/2003. Double-T Sill was placed at seaward end of compartment (around 700 ft) but units settled into bed before first postinstallation profile (4/2003) was surveyed

Figure 39. Cell 6 representative profile changes (continued)

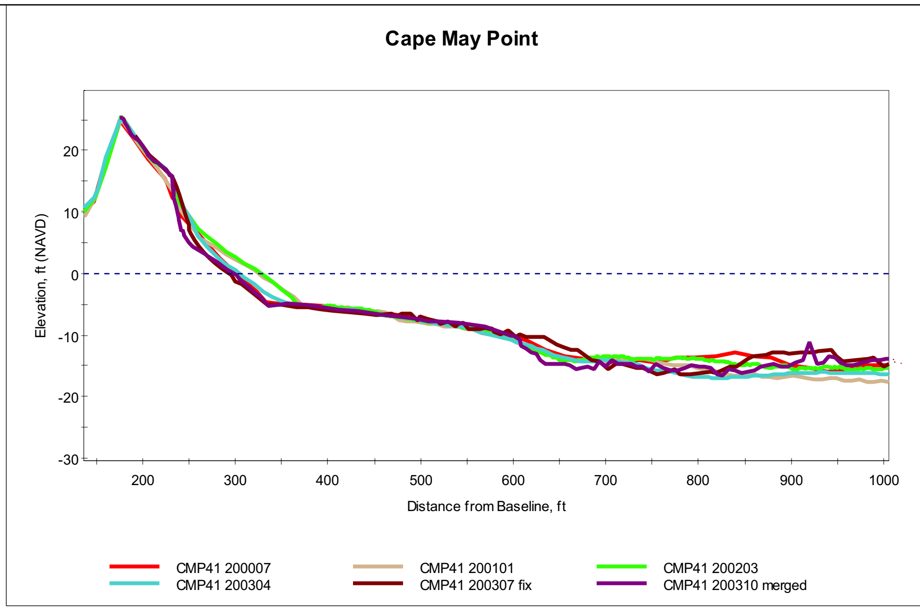


b. Line CMP38 from 7/2000 to 10/2003. The Double-T Sill was placed at about 684 ft, but also settled into bed before first postinstallation profile (4/2003) was surveyed

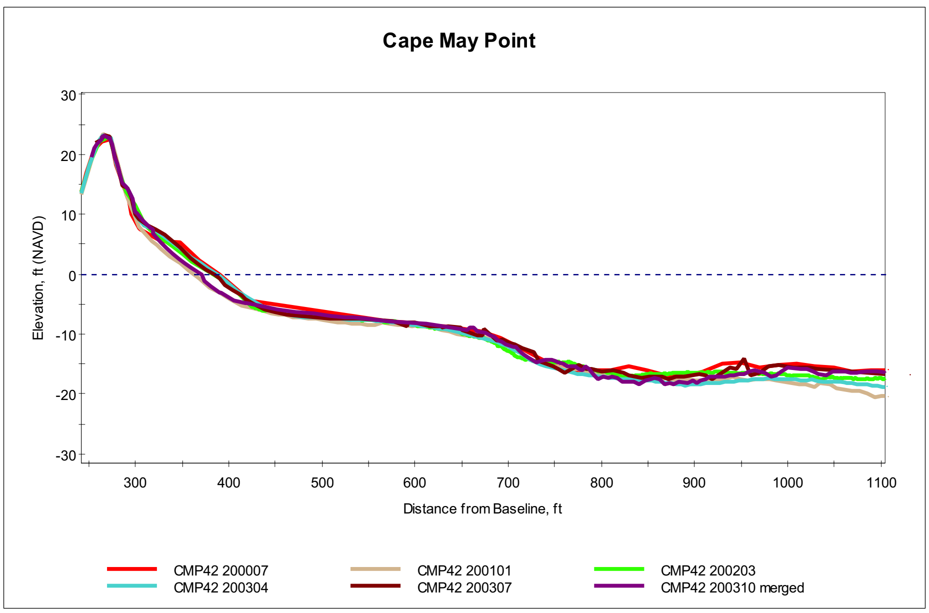


c. Close-up of profile changes in area of Double-T on Line CMP37 showing slight mound over location of submerged structure. 3/2002 is preinstallation and other three dates are postinstallation

Figure 39. (concluded)

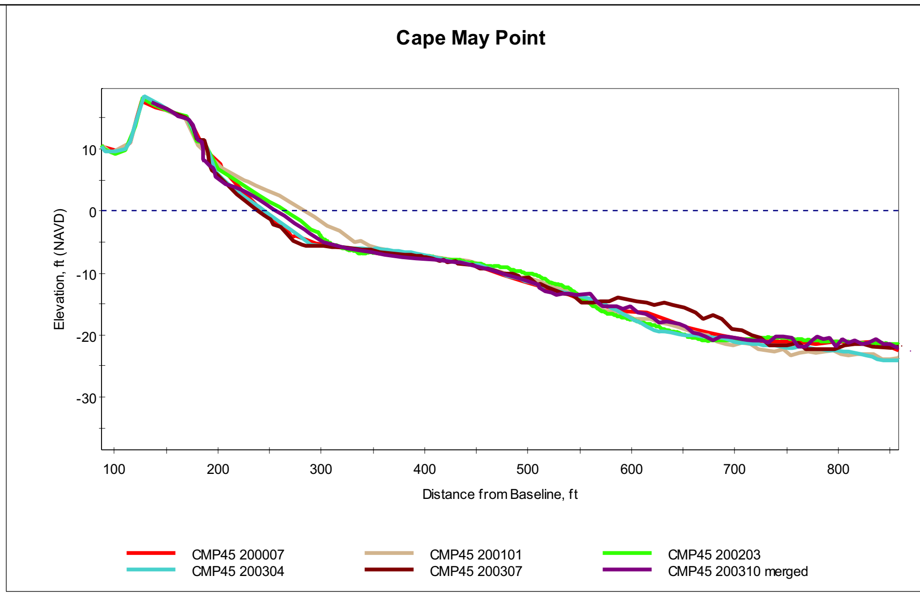


a. Line CMP41 from 7/2000 to 10/2003. Cell 7, western control cell has no structures. Berm on this eastern side profile has lost sand

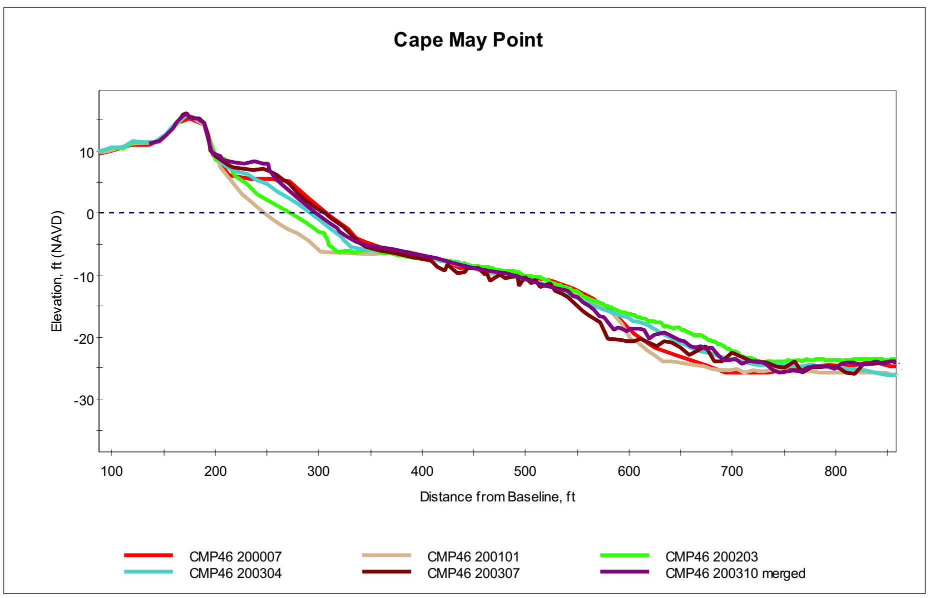


b. Line CMP42 from 7/2000 to 10/2003. Western side of control Cell 7 shows a gain in sand on berm

Figure 40. Cell 7 representative profile changes



a. Cell 8 representative profile changes on Line CMP45 from 7/2000 to 10/2003. Berm on eastern side of this control compartment has lost sand



b. Line CMP46 from 7/2000 to 10/2003. Berm on western side of this control compartment has gained sand

Figure 41. Cell 8 representative profile changes

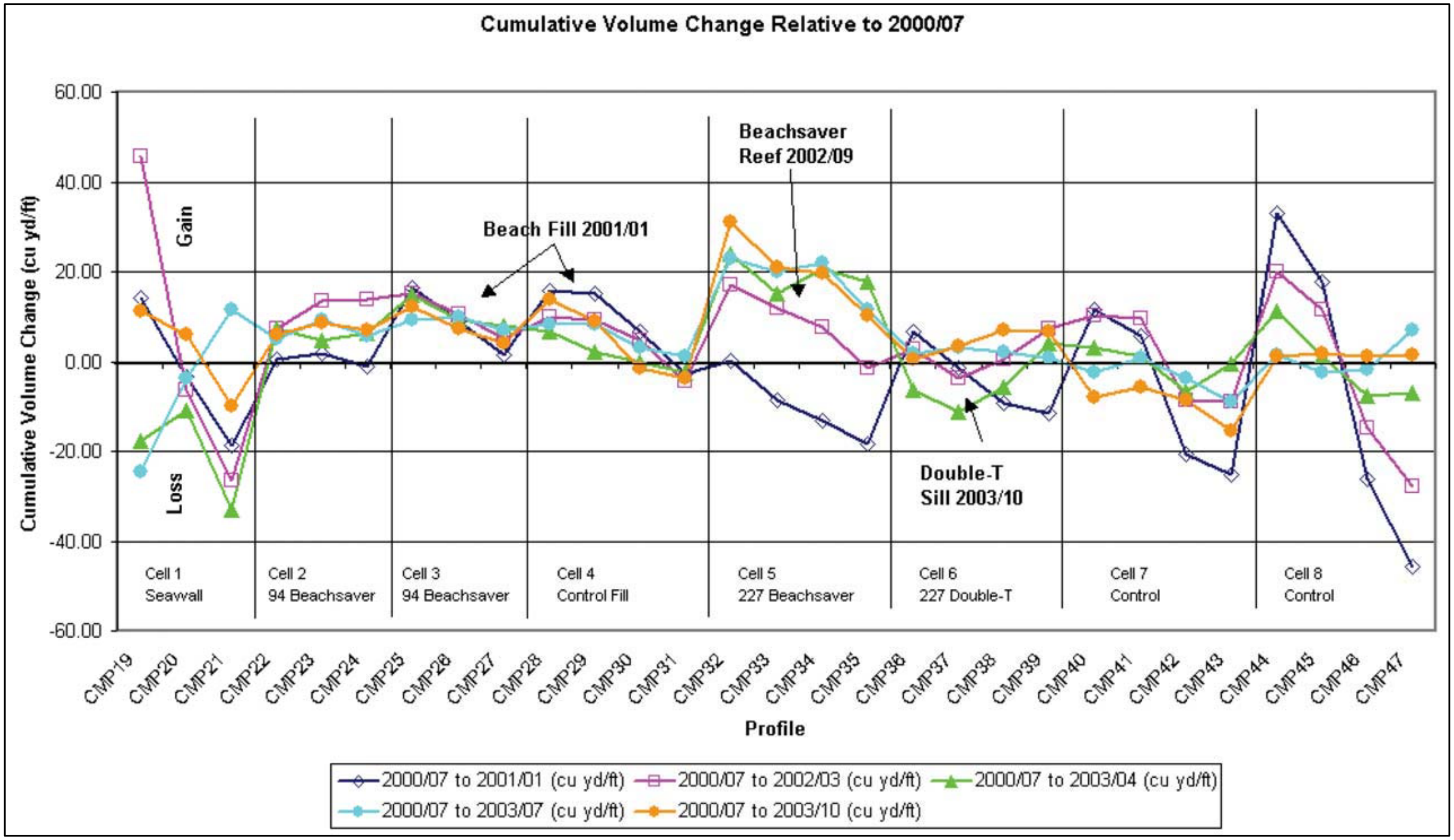
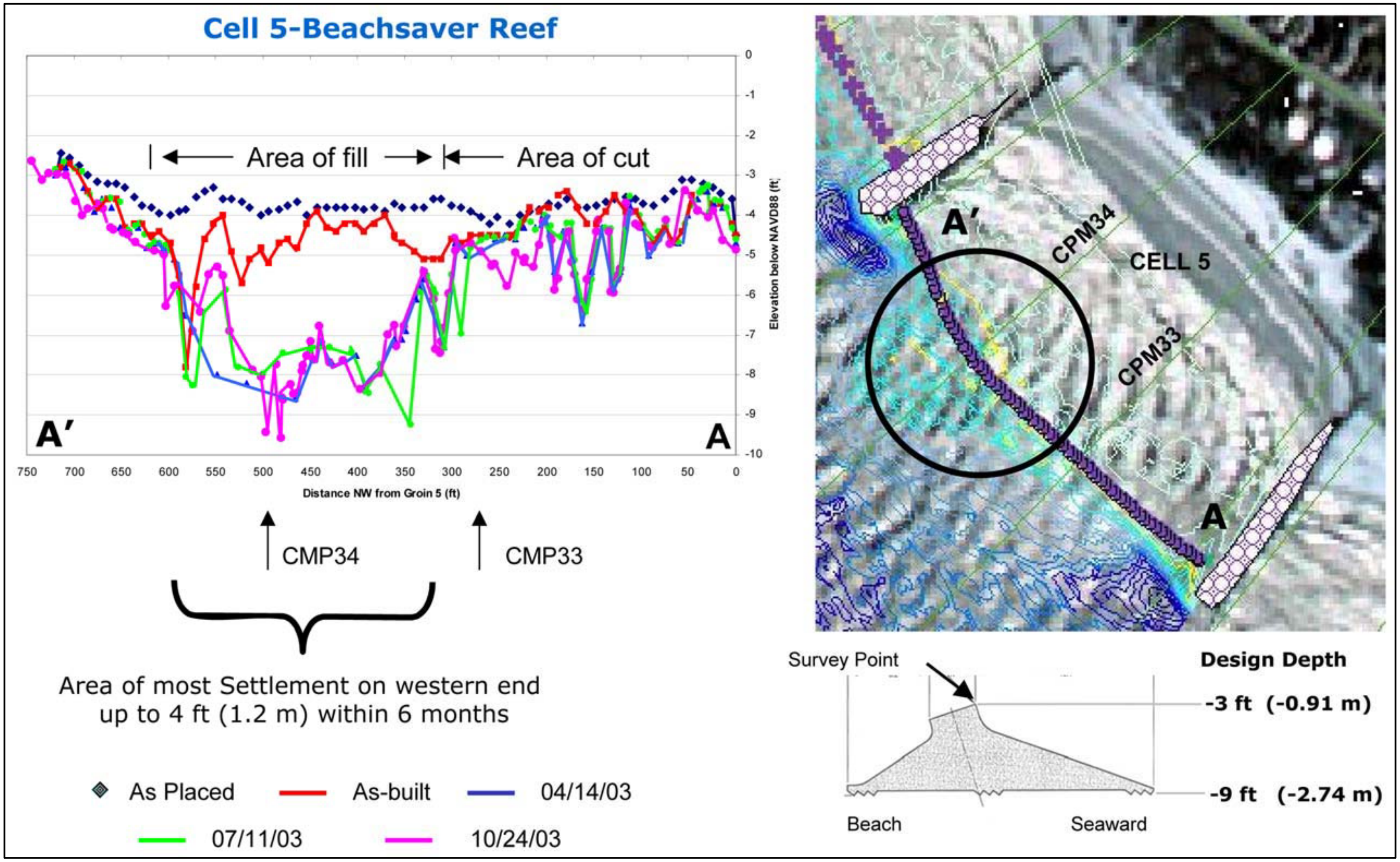
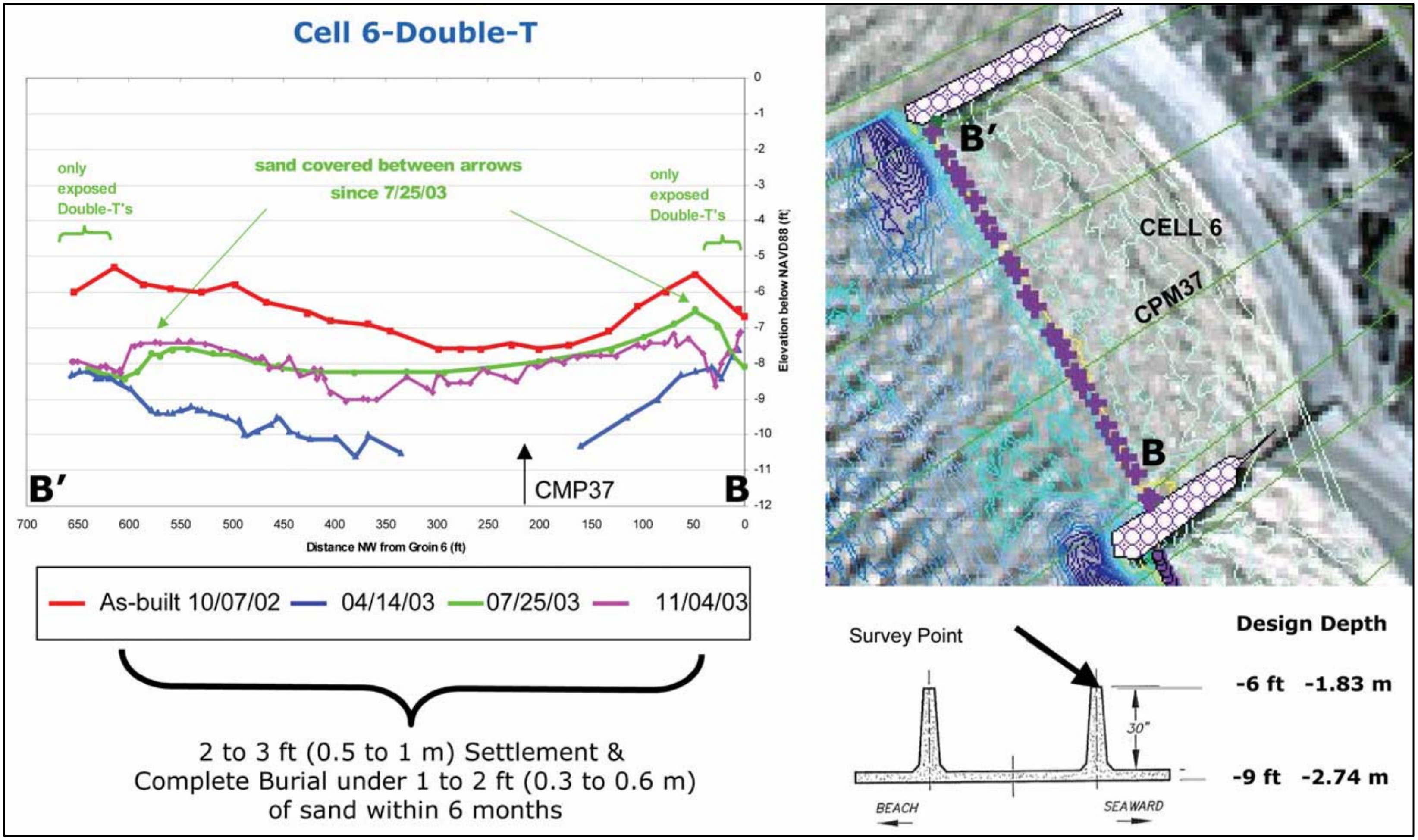


Figure 42. Cumulative volume change since July 2000 on each profile line relative to July 2000



a. Settlement of Beachsaver Reef in cell 5. Measurements made from top edge of Beachsaver Reef as shown by arrows

Figure 43. Measurements of settlement (continued)



b. Settlement of Double-T Sill. Measurements made from top of seaward Double-T sill as shown by arrows

Figure 43. (concluded)

Figure 44. Photo showing exposed tops of west end units of Beachsaver Reef and rock placed to tie units into groin around time of low tide. Swimmers with rod are over units that have settled

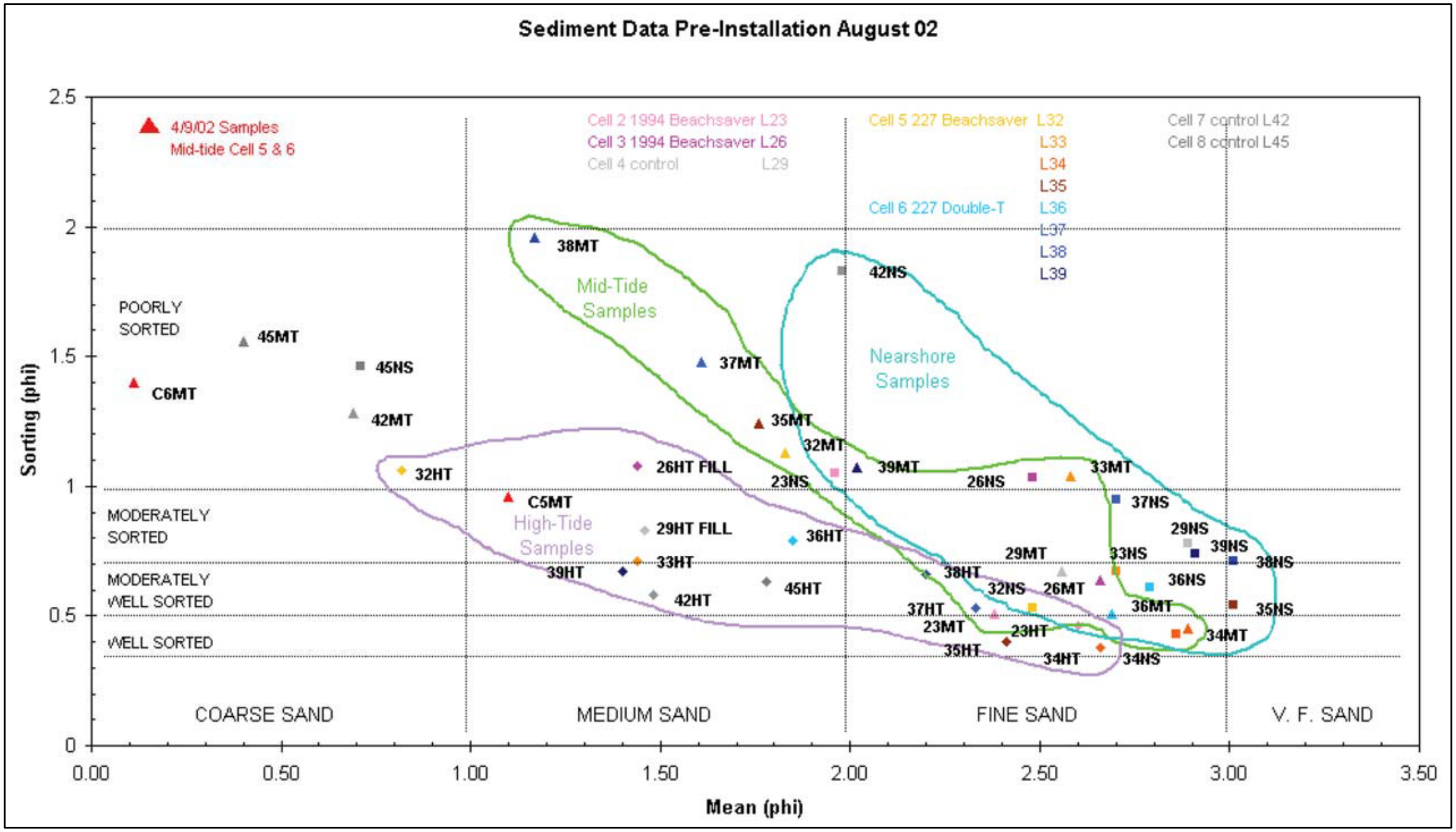


Figure 45. Mean vs. sorting plot of preinstallation sediment samples (8/02)

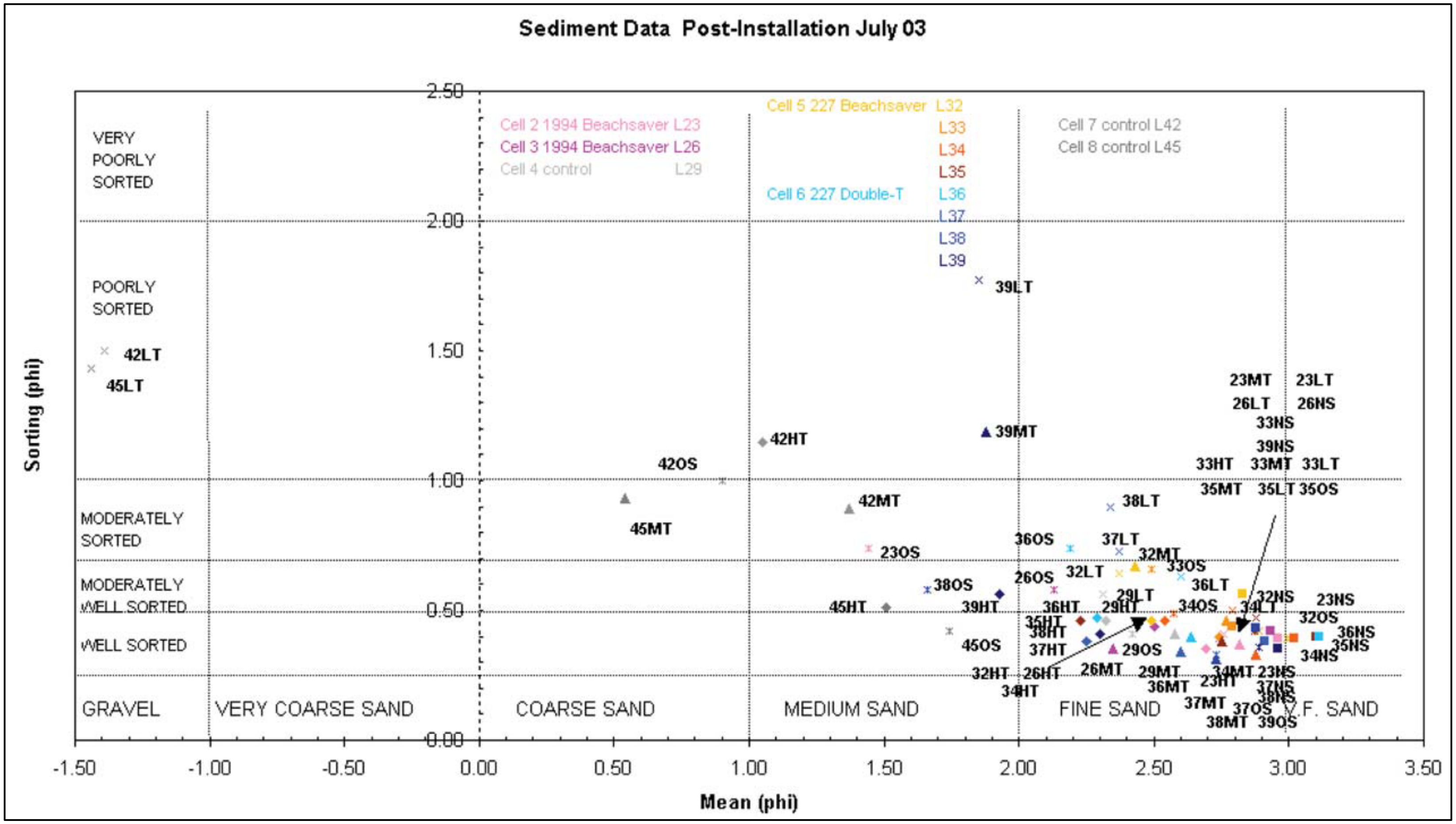


Figure 46. Mean vs. sorting plot of postinstallation sediment samples (7/03)

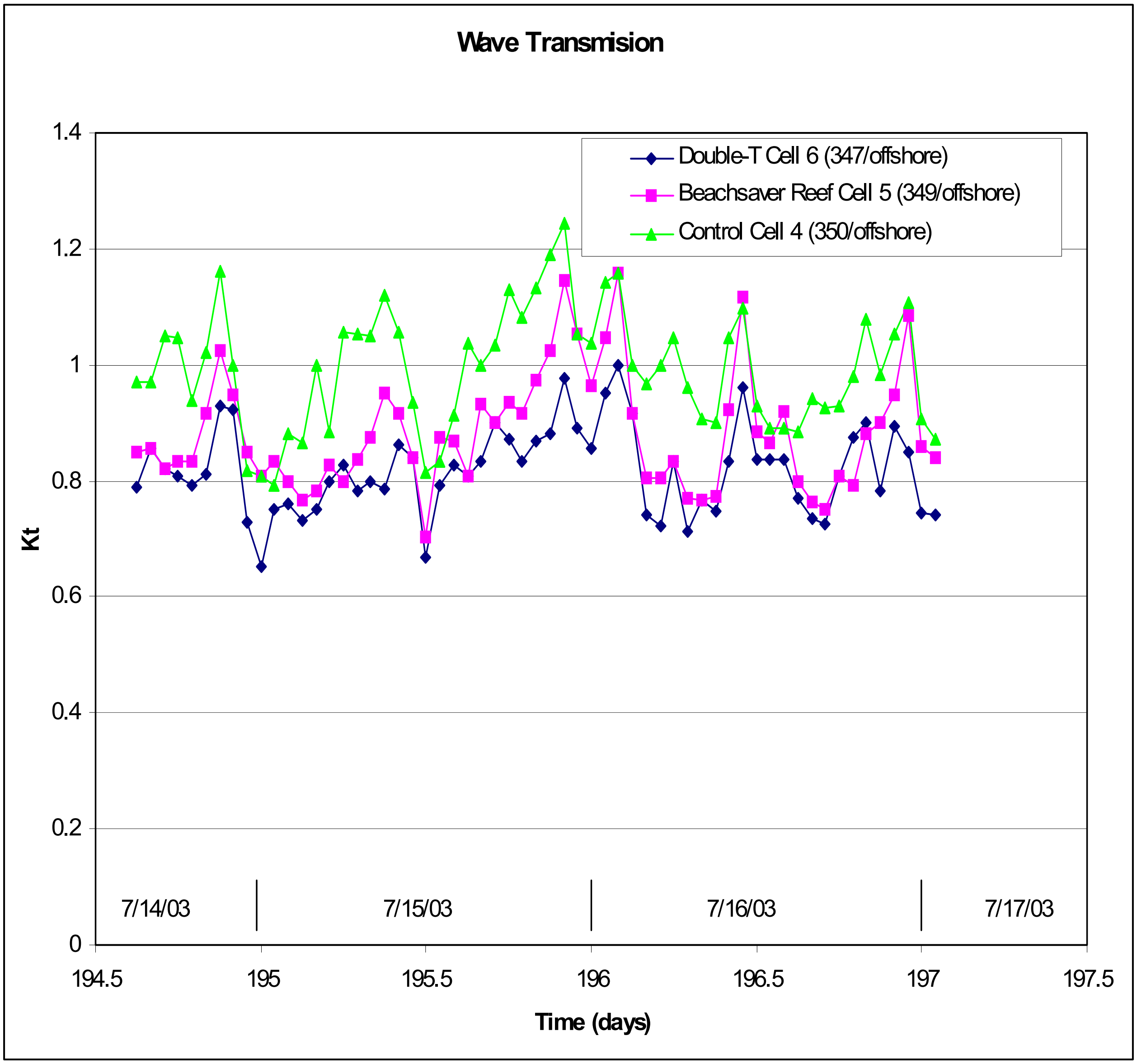


Figure 47. Wave transmission calculations from three cell wave gages relative to offshore gage

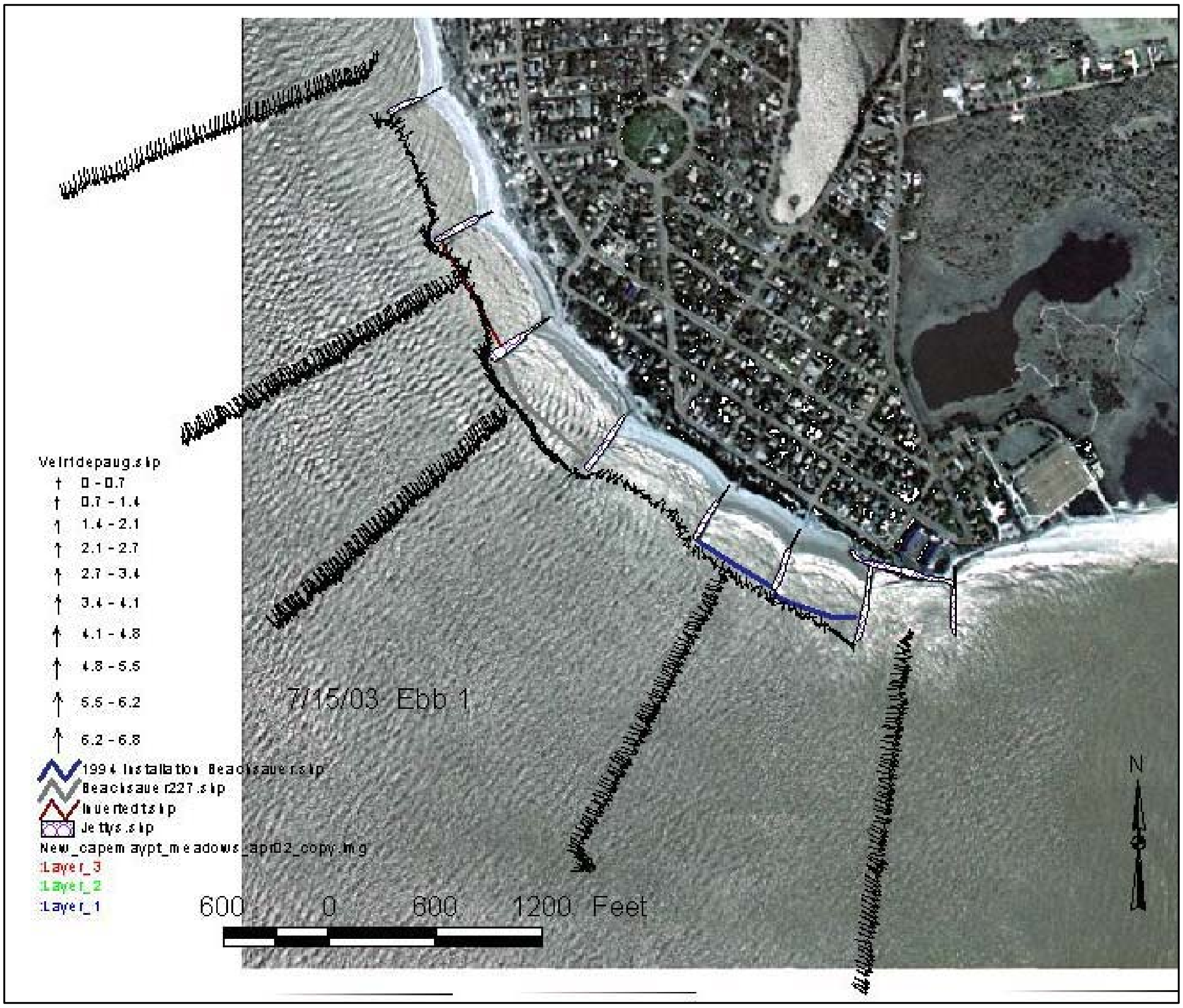


Figure 48. Depth averaged ADCP current velocity vectors for first ebb current survey on 7/15/03 at 1200. Velocity in feet per second

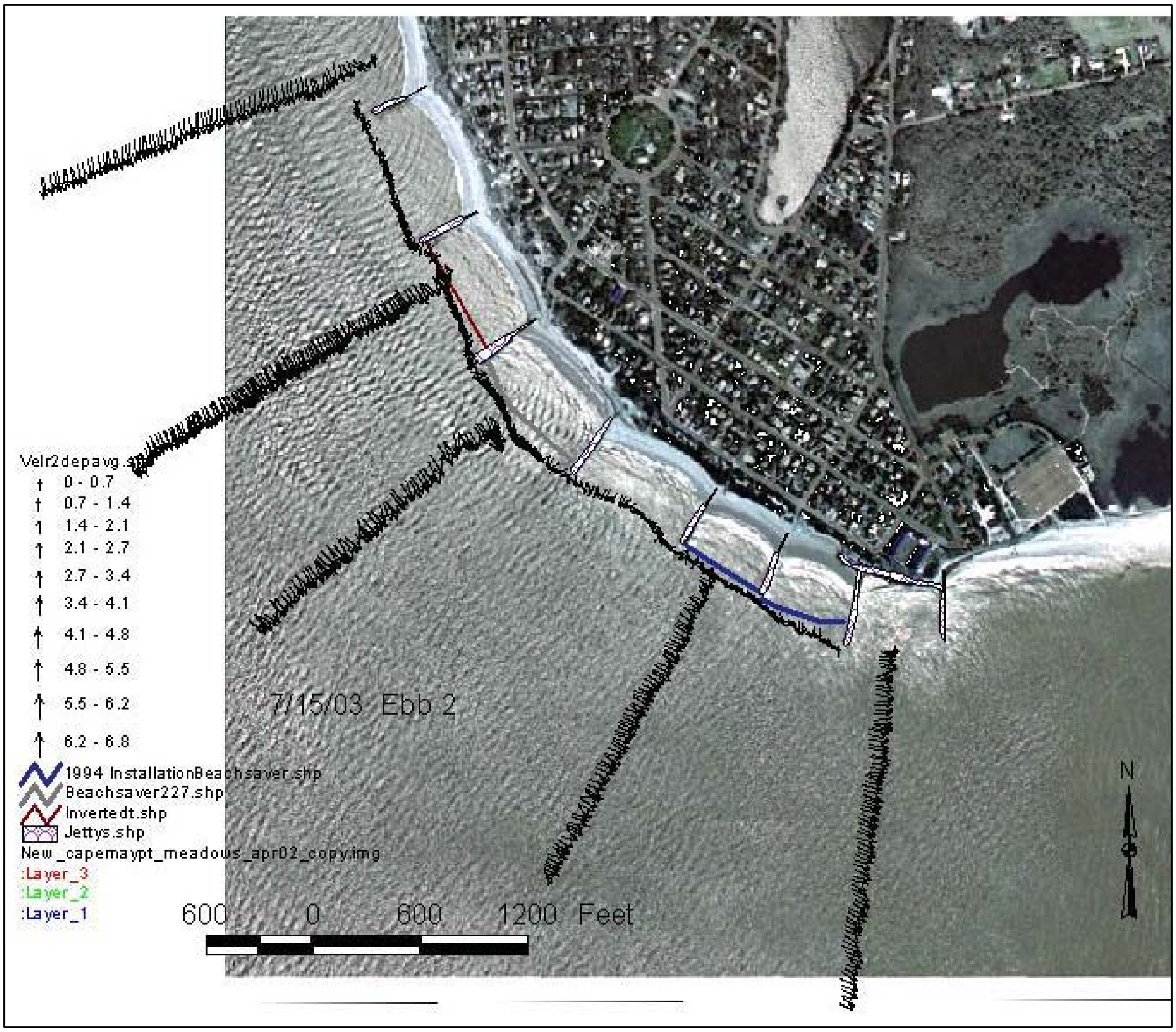


Figure 49. Depth averaged ADCP current velocity vectors for second ebb current survey on 7/1 5/03 at 1300. Velocity in feet per second

Figure 50. Depth averaged ADCP current velocity vectors for third ebb current survey on 7/15/03 at 1400. Velocity in feet per second

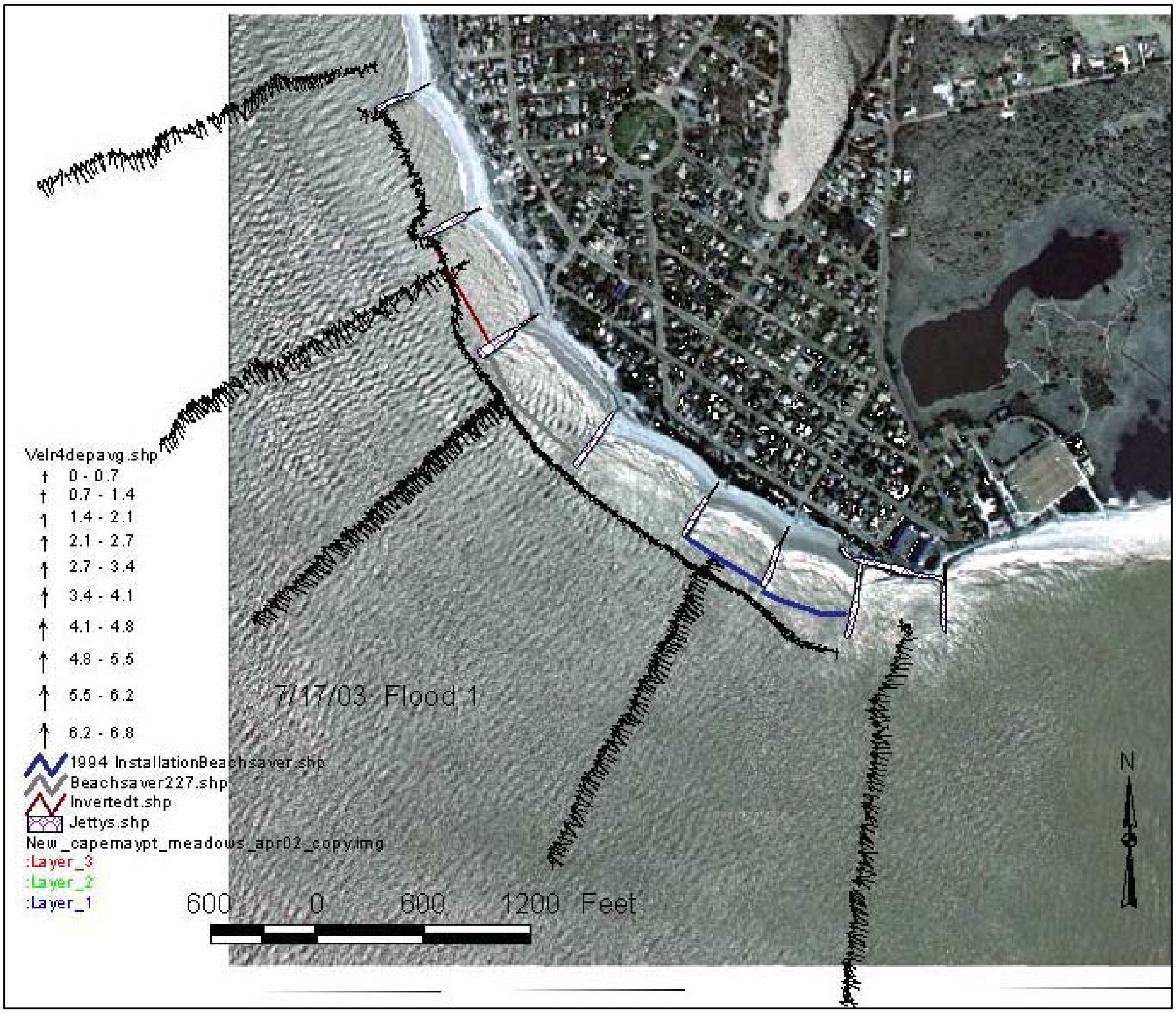


Figure 51. Depth averaged ADCP current velocity vectors for first flood current survey on 7/17/03 at 0900. Velocity in feet per second

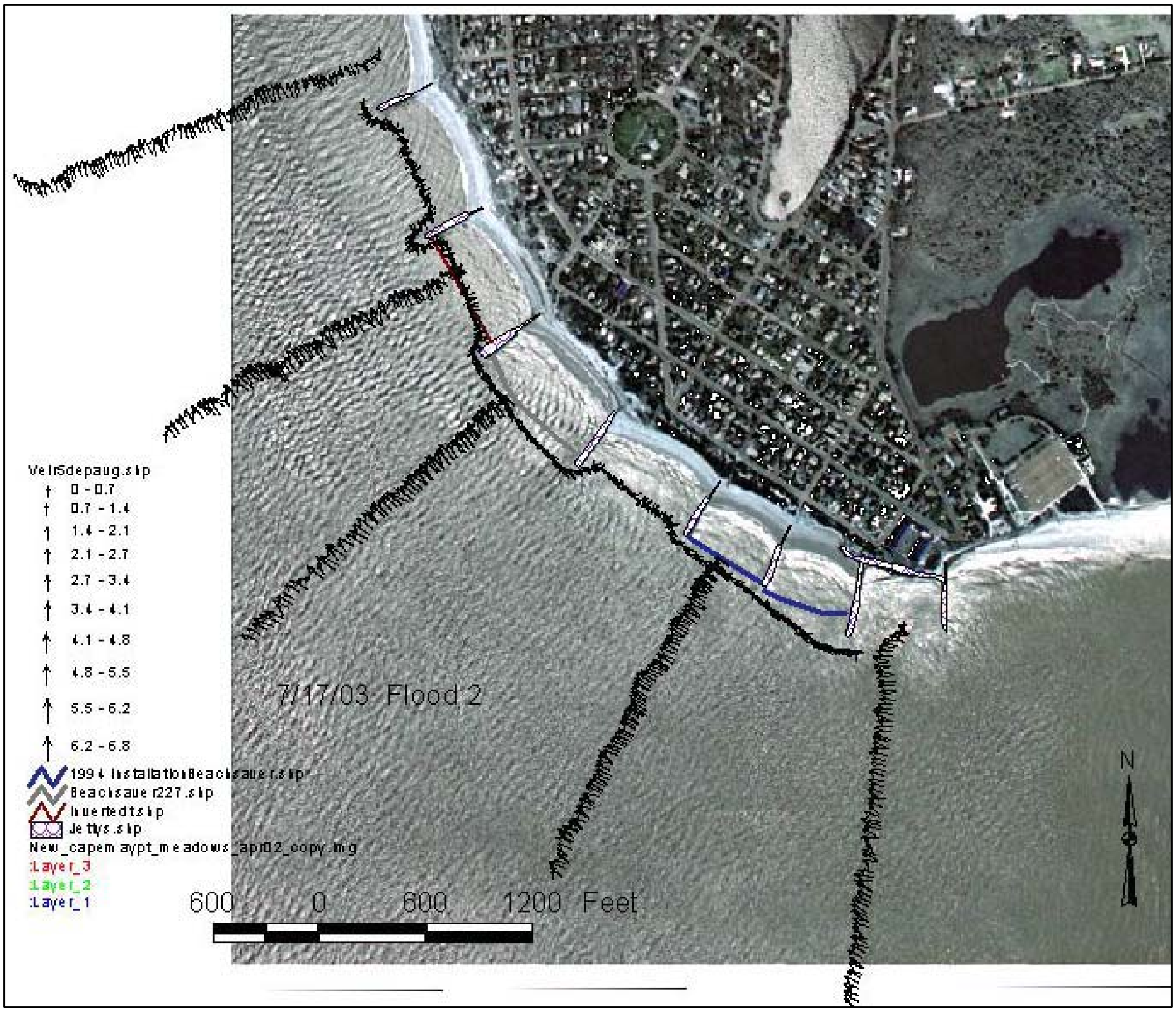


Figure 52. Depth averaged ADCP current velocity vectors for second flood current survey on 7/17/03 at 1000. Velocity in feet per second

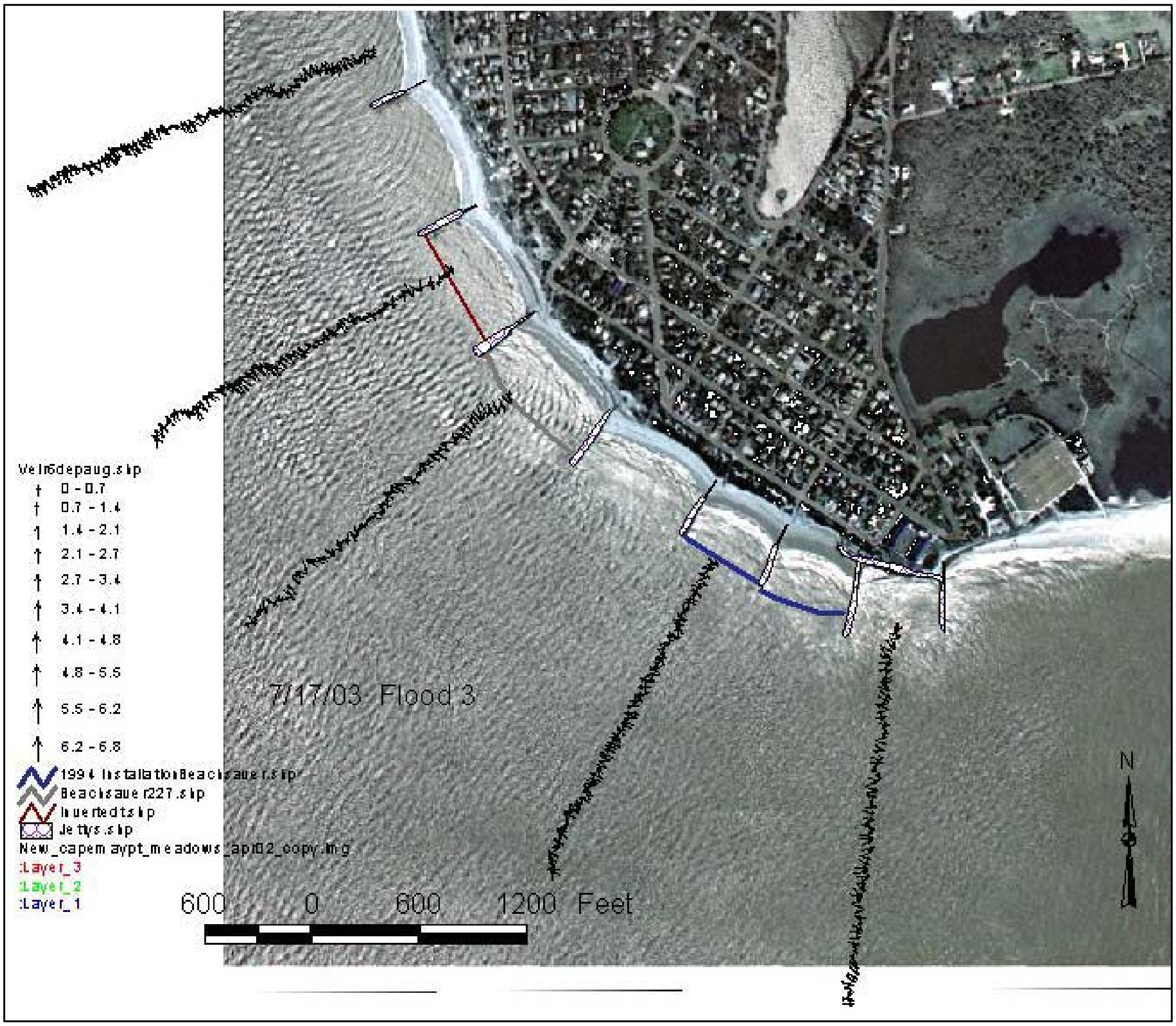


Figure 53. Depth averaged ADCP current velocity vectors for third flood current survey on 7/17/03 at 1130. Velocity in feet per second. Note: Line 6 was not run due to proximity to high slack water

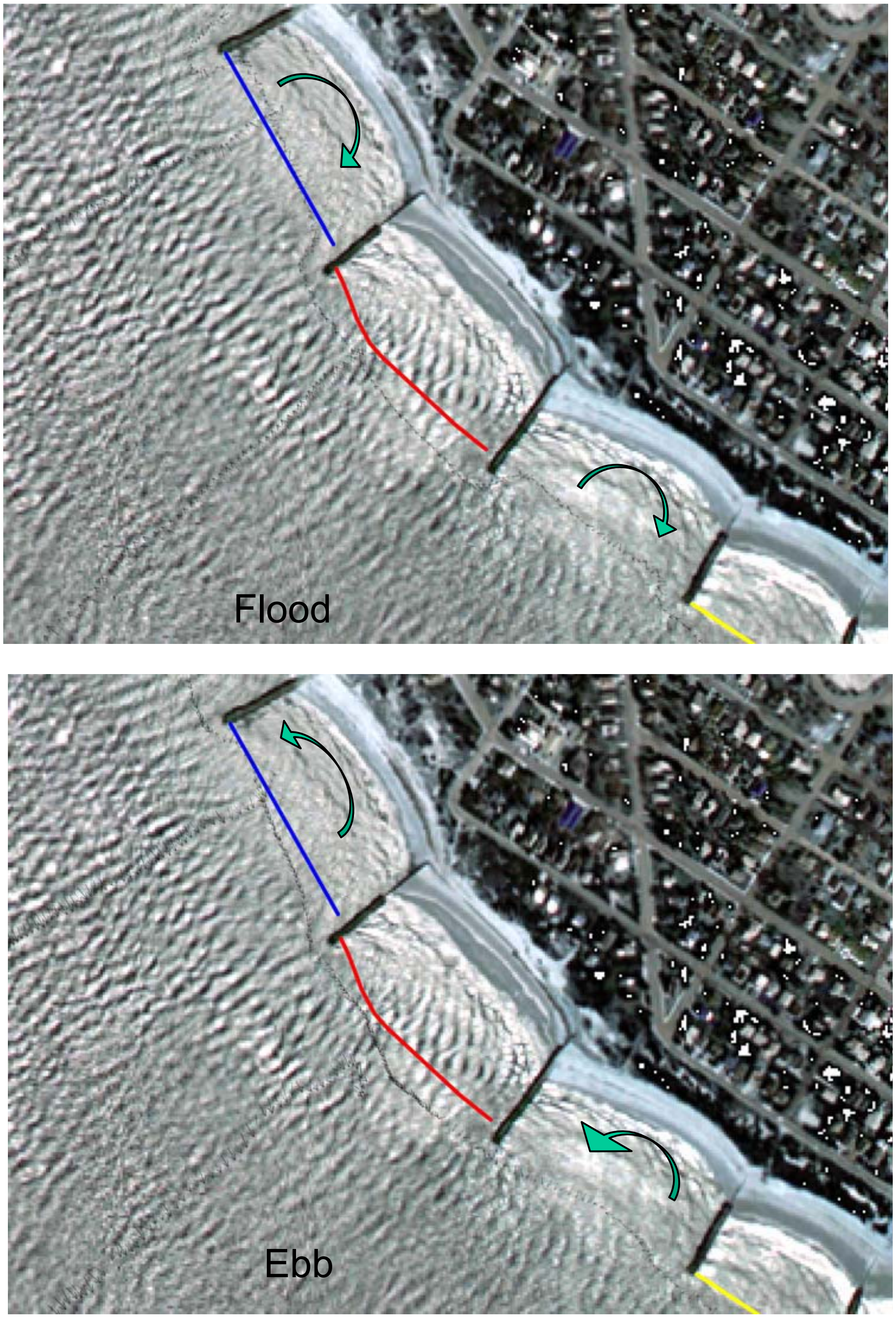


Figure 54. Schematic of idealized flow within cells on flood and ebb based on observations of debris flow and ADCP measurements at seaward end of cells

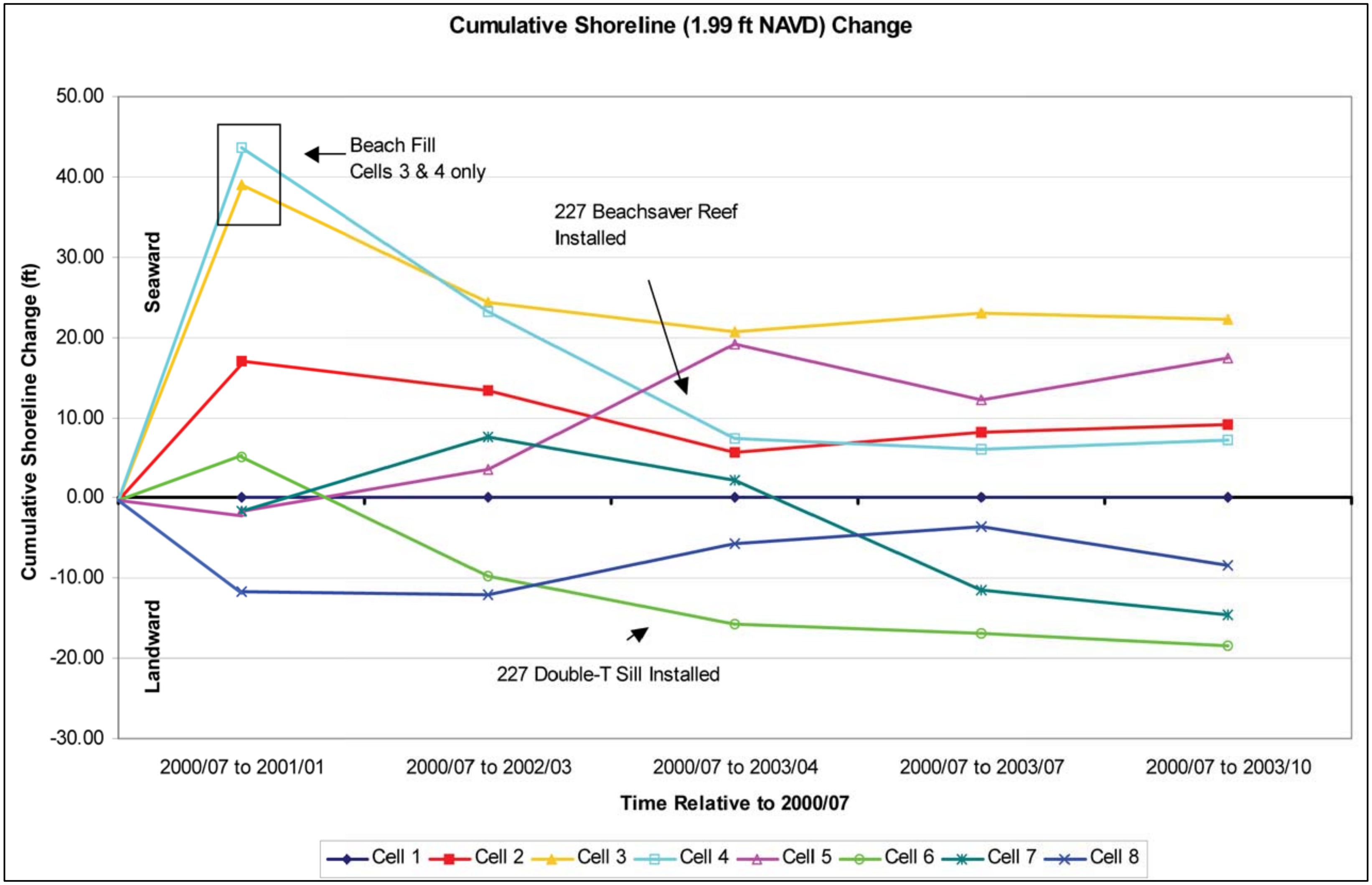


Figure 55. Cumulative shoreline change for each cell over study relative to 7/2000 shoreline

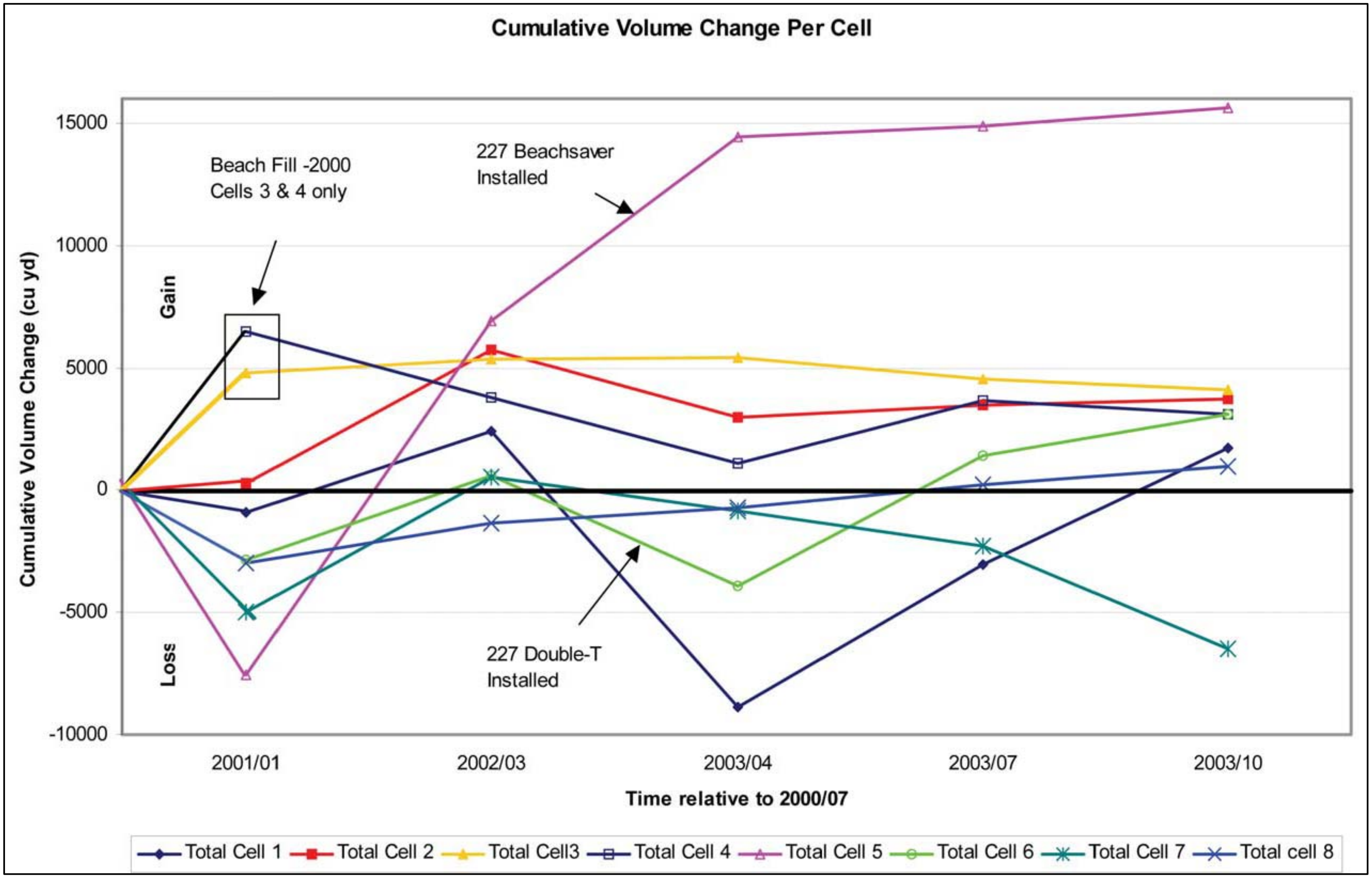


Figure 56. Cumulative volume change for each cell over study period relative to 7/2000

Appendix A
Sediment Analysis

Sediment Variation by Cell

Table A1 provides the grain-size statistics for the preinstallation sediment from April and August 2002. Table A2 provides the grain-size statistics for the postinstallation sediments from July 2003. The sediment statistics are calculated using the method of moments and listed in phi units (ϕ). The conversion from phi to millimeters uses the following formula:

$$d_{mm} = e^{-\phi ln2} = 1\ \text{mm}(2^{(-\phi)}) \qquad (2)$$

where d_{mm} is the particle diameter in millimeters, ϕ is the particle diameter in phi units, e is equal to 2.718281 and $ln2$ is equal to 0.693147.

Line 23 was the center profile line in cell 2, which contained the 1994 Beachsaver Reef™. The sediments in this cell will provide changes in sediment for the well established existing breakwater. Figure A1 shows the grain-size frequency plots for all of the pre- and post-227 project installation sediment samples. The solid lines are the three preinstallation samples from high tide (HT), midtide (MT), and nearshore (NS). The dotted lines are the postinstallation samples from HT, MT, low tide (LT), NS, and offshore (OS) of the structures. A coarse to medium sand component was found in the preinstallation NS sample and the postinstallation offshore sample outside of the breakwater. The rest of the samples can be characterized as fine to very fine, well-sorted sands outside of the breakwater. The rest of the samples can be characterized as fine to very fine well-sorted sands.

Table A1
Sediment Data Preinstallation, August 2002

Cell/Profile		Position	Date	Mean	Mode	Bimodal	Median	Std Dev	Skewness	Kurtosis
Cell 5		Midtide	4/9/2002	1.10	1.25		1.11	0.96	-0.45	4.00
Cell 6		Midtide	4/9/2002	0.11		-2.0/0.25/1.0	0.16	1.40	0.04	2.18
Cell 2	CMP23	High Tide	8/22/2002	2.60	2.75		2.64	0.46	-0.72	5.22
		Midtide	8/22/2002	2.38	2.75		2.46	0.51	-0.60	2.90
		Nearshore	8/22/2002	1.96		2.75/1.00	2.53	1.05	-0.86	2.65
Cell 3	CMP 26	High Tide	8/22/2002	1.44	2.25		1.58	1.08	-0.26	2.44
		Midtide	8/22/2002	2.66	3.00		2.80	0.64	-1.76	8.19
		Nearshore	8/22/2002	2.48		3.25/1.00	2.86	1.03	-1.50	4.80
Cell 4	CMP 29	High Tide	8/22/2002	1.46	1.00		1.30	0.83	0.64	3.29
		Midtide	8/22/2002	2.56	3.00		2.71	0.67	-1.86	9.60
		Nearshore	8/22/2002	2.89	3.00		3.02	0.78	-3.31	15.80
Cell 5	CMP 32	High Tide	8/22/2002	0.82	1.25		1.05	1.06	-0.93	3.89
		Midtide	8/22/2002	1.83		2.75/1.00	2.36	1.13	-0.73	2.55
		Nearshore	8/22/2002	2.48	2.75		2.50	0.53	-3.33	24.91
	CMP 33	High Tide	8/22/2002	1.44	1.25		1.43	0.71	-0.65	5.82
		Midtide	8/22/2002	2.58	3.25		2.87	1.04	-2.47	8.90
		Nearshore	8/22/2002	2.70	2.75		2.76	0.67	-3.03	19.03
	CMP 34	High Tide	8/22/2002	2.66	2.75		2.66	0.38	-0.92	8.70
		Midtide	8/22/2002	2.89	3.25		2.95	0.45	-2.45	16.38
		Nearshore	8/22/2002	2.86	2.87		2.89	0.43	-0.74	6.21
	CMP 35	High Tide	8/22/2002	2.41	2.75		2.42	0.40	-0.25	4.98
		Midtide	8/22/2002	1.76		3.00/1.00	2.05	1.24	-0.31	1.80
		Nearshore	8/22/2002	3.01	3.25		3.08	0.54	-2.35	15.63
Cell 6	CMP 36	High Tide	8/22/2002	1.85		2.25/1.00	1.96	0.79	-0.49	2.79
		Midtide	8/22/2002	2.69	2.87		2.76	0.51	-1.96	10.38
		Nearshore	8/22/2002	2.79	3.00		2.86	0.61	-3.67	24.01
	CMP 37	High Tide	8/22/2002	2.33	2.75		2.37	0.53	-2.03	16.61
		Midtide	8/22/2002	1.61		3.00/1.00	2.02	1.48	-0.88	3.02
		Nearshore	8/22/2002	2.70	3.25		2.95	0.95	-2.66	10.32
	CMP 38	High Tide	8/22/2002	2.20	2.75		2.29	0.66	-2.14	11.93
		Midtide	8/22/2002	1.17		3.00/ -2.00/1.00	1.92	1.96	-0.51	1.73
		Nearshore	8/22/2002	3.01	3.25		3.12	0.71	-4.59	28.17
	CMP 39	High Tide	8/22/2002	1.40	1.00		1.37	0.67	-0.23	4.54
		Midtide	8/22/2002	2.02		2.75/1.00	2.35	1.07	-0.92	3.44
		Nearshore	8/22/2002	2.91	3.00		2.98	0.74	-4.44	26.00
Cell 7	CMP 42	High Tide	8/22/2002	1.48	1.25		1.48	0.58	-0.16	4.48
		Midtide	8/22/2002	0.69		1.00/-2.00	1.00	1.28	-0.89	3.22
		Nearshore	8/22/2002	1.98		3.00/-2.00	2.84	1.83	-1.34	3.09
Cell 8	CMP 45	High Tide	8/22/2002	1.78	2.00		1.84	0.63	-1.34	8.69
		Midtide	8/22/2002	0.40		-2.00/1.80	0.74	1.56	-0.22	1.79
		Nearshore	8/22/2002	0.71		-2.00/1.25	1.15	1.46	-0.80	2.53

Note: Statistics calculated using method of moments (units in phi).

Table A2
Sediment Data Postinstallation, July 2003

Cell/Profile		Position	Date	Mean	Mode	Bimodal	Median	Std Dev	Skewness	Kurtosis
Cell 2	CMP 23	High Tide	7/21/2003	2.69	2.61		2.69	0.35	0.08	3.26
		Midtide	7/21/2003	2.82	2.87		2.84	0.37	-0.54	4.54
		Low Tide	7/21/2003	2.76	2.87		2.77	0.41	-0.70	5.22
		Nearshore	7/21/2003	2.96	2.87		2.94	0.39	-0.26	4.68
		Offshore	7/17/2003	1.44		1.12/1.87	1.39	0.74	0.11	3.06
Cell 3	CMP 26	High Tide	7/21/2003	2.50	2.36		2.51	0.44	-1.06	7.61
		Midtide	7/21/2003	2.35	2.36		2.38	0.35	-1.42	8.14
		Low Tide	7/21/2003	2.74	2.87		2.78	0.39	-1.09	7.08
		Nearshore	7/21/2003	2.93	2.87		2.95	0.42	-2.13	16.29
		Offshore	7/17/2003	2.13	2.12		2.19	0.58	-1.09	5.65
Cell 4	CMP 29	High Tide	7/21/2003	2.32	2.12		2.30	0.46	-0.27	4.16
		Midtide	7/21/2003	2.58	2.61		2.61	0.41	-0.68	5.50
		Low Tide	7/21/2003	2.31	2.36		2.35	0.56	-0.65	4.40
		Nearshore	no sample							
		Offshore	7/17/2003	2.42		2.36/2.87	2.37	0.41	-0.04	5.91
Cell 5	CMP 32	High Tide	7/11/2003	2.49		2.36/2.87	2.47	0.46	-0.71	4.44
		Midtide	7/11/2003	2.43		2.87/2.36	2.58	0.67	-1.07	4.01
		Low Tide	7/11/2003	2.37	2.87		2.49	0.64	-0.92	4.12
		Beachsaver (Landward)	7/11/2003	2.83	2.87		2.89	0.56	-1.85	9.93
		Offshore	7/17/2003	2.99	2.87		2.94	0.39	-0.30	6.71
	CMP 33	High Tide	7/11/2003	2.74	2.87		2.80	0.40	-1.12	5.88
		Midtide	7/11/2003	2.77	2.87		2.83	0.46	-2.08	11.32
		Low Tide	7/11/2003	2.89	2.87		2.93	0.42	-2.30	13.10
		Beachsaver (Landward)	7/11/2003	2.79	2.87		2.83	0.44	-0.87	6.58
		Offshore	7/17/2003	2.49	2.61		2.59	0.66	-1.32	5.96
	CMP 34	High Tide	7/11/2003	2.54	2.87		2.61	0.46	-0.60	3.47
		Midtide	7/11/2003	2.88	2.87		2.89	0.33	-1.22	8.8
		Low Tide	7/11/2003	2.79	2.87		2.86	0.50	-1.64	7.26
		Beachsaver (Landward)	7/11/2003	3.02	2.87		3.01	0.39	-0.98	8.65
		Offshore	7/17/2003	2.57	2.61		2.61	0.49	-0.70	4.80
	CMP 35	High Tide	7/11/2003	2.23	2.12		2.21	0.46	0.10	3.28
		Midtide	7/11/2003	2.75	2.87		2.80	0.38	-1.27	8.37
		Low Tide	7/11/2003	2.88	2.87		2.91	0.47	-3.30	21.42
		Beachsaver (Landward)	7/11/2003	3.10		2.87/3.86	3.08	0.40	-0.84	10.65
		Offshore	7/17/2003	2.87	2.87		2.87	0.42	-0.62	6.97

(Continued)

Table A2 (Concluded)										
Cell/Profile		**Position**	**Date**	**Mean**	**Mode**	**Bimodal**	**Median**	**Std Dev**	**Skewness**	**Kurtosis**
Cell 6	CMP 36	High Tide	7/11/2003	2.29	2.12		2.29	0.47	-0.37	3.85
		Midtide	7/11/2003	2.64	2.87		2.70	0.40	-0.88	5.54
		Low Tide	7/11/2003	2.60	2.87		2.77	0.63	-1.54	5.75
		Dbl-T Sill (Landward)	7/11/2003	3.11		3.12/3.86	3.10	0.40	-0.60	7.84
		Offshore	7/17/2003	2.19		2.61/1.12	2.35	0.74	-0.75	3.16
	CMP 37	High Tide	7/11/2003	2.25	2.12		2.23	0.38	-0.03	3.62
		Midtide	7/11/2003	2.60	2.61		2.62	0.34	-0.53	4.87
		Low Tide	7/11/2003	2.37	2.87		2.53	0.73	-1.76	6.41
		Dbl-T Sill (Landward)	7/11/2003	2.91	2.87		2.90	0.38	-0.42	8.01
		Offshore	7/17/2003	2.73	2.87		2.75	0.33	-0.67	7.80
	CMP 38	High Tide	7/11/2003	2.30	2.12		2.28	0.41	-0.11	3.49
		Midtide	7/11/2003	2.73	2.87		2.76	0.31	-0.44	4.38
		Low Tide	7/11/2003	2.34	2.87		2.61	0.90	-1.64	5.07
		Dbl-T Sill (Landward)	7/11/2003	2.88		2.87/2.36	2.89	0.43	-0.65	7.05
		Offshore	7/17/2003	1.66		1.36/2.87	1.56	0.58	0.80	3.67
	CMP 39	High Tide	7/11/2003	1.93	1.87		1.93	0.56	0.10	3.00
		Midtide	7/11/2003	1.88		2.87/1.12	2.19	1.19	-1.89	7.00
		Low Tide	7/11/2003	1.85	2.87		2.63	1.77	-1.50	3.85
		Dbl-T Sill (Landward)	7/11/2003	2.96	2.87		2.94	0.35	-1.08	9.94
		Offshore	7/17/2003	2.89	2.87		2.90	0.36	-1.00	9.82
Cell 7	CMP 42	High Tide	7/21/2003	1.05		1.87/-0.63/-0.12	1.38	1.15	-1.06	3.38
		Midtide	7/21/2003	1.37	1.36		1.49	0.89	-1.76	7.06
		Low Tide	7/21/2003	-1.39		-1.62/-1.12/-0.63	-1.77	1.50	0.86	3.18
		Nearshore	no sample							
		Offshore	7/17/2003	0.90	1.12		1.12	1.00	-1.62	6.03
Cell 8	CMP 45	High Tide	7/21/2003	1.51	1.37		1.48	0.51	-0.26	5.31
		Midtide	7/21/2003	0.54		1.12/-0.63	0.71	0.93	-0.81	4.09
		Low Tide	7/21/2003	-1.44		-1.87/1.12/-1.12	-1.78	1.43	0.52	2.31
		Nearshore	no sample							
		Offshore	7/17/2003	1.74	1.87		1.77	0.42	-0.45	8.25

Note: Statistics calculated using method of moments (units in phi).

Figure A2 shows the grain-size frequency plots for the pre- and post-227 project installation sediment samples for the center profile line in cell 3. Cell 3 contains the second 1994 Beachsaver Reef and will show the changes in sediment for this well established breakwater, as well as the response to a beach fill that was placed in December 2000. The 8/02 sample from the HT consisted of relatively undisturbed beach-fill material, based on grain size and color. The fill material was taken from an upland sand quarry and was coarser and more poorly sorted than the native beach sands. It also had a distinctive yellow iron stained color that is easily distinguished from the native tan to gray beach sands. The fill sand at high water has been on the beach for about 2 years and has not been reworked by wave action. The grain-size distribution has a unique shape of a coarse, poorly sorted sand. The wave action has resorted the 8/02 MT and NS samples over the 2 years into a more native very fine tan to gray sand, with some coarse fill material. The dotted line samples from 7/03 show that the sediment

has resorted over the winter and now all samples have a more native like well-sorted fine to very fine sand. The coarsest material was found in the offshore sample, which is located seaward for the breakwater and is more influenced by the strong tidal currents. The finer material is deposited in the relatively protected groin compartment.

The eastward control cell 4 is represented by samples collected on the center profile line 29 (Figure A3). The beach fill was also placed in this cell and the 8/02 HT sample has a distinctive medium sand distribution and yellow color of the fill material. The MT and NS samples have been more reworked by the waves over the 2-year interval since placement and are more well sorted and composed of fine to very fine sands. The 7/03 dotted line samples are all reworked and are fine to very fine well-sorted sands. As in cell 3, the HT samples have been reworked by storm waves over the winter of 02/03 into a more native distribution.

All four profile lines in cell 5 were sampled for sediment since they were in the cell where the 227 Project Beachsaver Reef was installed. Figures A4 to A7 show the grain-size distributions of samples collected on profile lines 32, 33, 34, and 35, respectively. The preinstallation HT and MT samples of lines 32 and HT sample of line 33 have a characteristically coarse to medium sand similar to the beach-fill material placed in the adjacent cell 4. No fill sand was placed in cell 5. However, at high water, waves commonly wash up over the beach in cell 4 and spill into cell 5 on the landward end of the groin, which changes from a wide rock construction to a thin wooden groin. Some fill material must have spilled over the narrow landward end of the wooden groin. The sample collected in April 2002 also has a similar medium sand grain-size distribution, which is different from the well-sorted fine to very fine sands found in the rest of the samples collected in both the pre- and postinstallation. The preinstallation MT sample on line 35 has a bimodal distribution with a coarse to medium sand component along with the more typical very fine sand component. Only line 34 has no coarse to medium sand material either in the pre- or postinstallation samples.

All four lines in cell 6 were sampled for sediment to document any changes in grain composition due to the installation of the 227 Project Double-T sill. In general, more coarse material was found on the native beaches beginning in this cell and progressing on the west side of Cape May Point beaches. The sediment grain-size distributions for profile lines 36, 37, 38, and 39 are shown in Figures A8 to A11, respectively. On line 36, the HT preinstallation sample showed a medium sand component, which shifted to a fine sand component after installation of the sill. The rest of the pre- and postinstallation samples all have a characteristic of well-sorted very fine sand. The MT sediment on line 37 had a coarse poorly sorted sand component in the April 2002 sample and that distribution continued in the August 2002 sample at this location. The rest of the pre- and postinstallation samples were either fine sand (HT) or very fine (all other samples on this profile line). Line 38 also had a large fine gravel component consisting of well-rounded pea size gravel in the MT preinstallation sediment. Postinstallation, the LT sample was composed of mainly medium sands, while both pre- and postinstallation HT samples were composed of fine sands. The rest of the pre- and postinstallation samples were predominately composed of the more common very fine sands (around 0.125 mm or 3.00 phi). Both the HT and MT samples on

line 39 had the coarser medium to fine sand components in both the pre- and postinstallation samples. The rest of the samples all had the common very fine sand distribution.

The west control sites consisting of cells 7 and 8 show an increase in fine gravel and coarse sand components. Each cell was represented by a single profile line located in the middle of the cell. Line 42 in cell 7 shows bimodal tendencies in most of the pre- and postinstallation samples with both fine gravel and medium sand components. The only very fine sand sample was the preinstallation nearshore sample (Figures A12). All of the samples in cell 8 (as represented by profile line 45) show a predominance of coarser more poorly sorted sample size distributions (Figure A13). These two western control cells have a distinctly different grain-size distribution both in the August 2002 and July 2003 sampling periods. The source of this coarse fraction could be from the interaction of waves and currents as the shoreline orientation enters more of a bay environment or be a lag deposit from relict in situ ancient river deposits.

Pre- and Postinstallation Change in Grain-Size Distribution

To assess any changes in sediment distributions from before and after the breakwater and sill structures were constructed, a comparison of the pre- and postinstallation sediment sample grain-size distributions was done. Due to the limited preinstallation sampling, only the HT, MT, and NS samples could be compared. Seven of the eight cells were sampled to get a picture of entire Cape May Point groin compartment sediment changes. The summer sampling of both sediment sets allowed for similar summer sediment distributions to be compared. The two winter type samples in April 2002 indicate that there is a seasonal component to the sediment change, with coarser sediment on the beach in the winter storm season and finer sands in the more fair weather summer months.

High tide

The high-tide samples for the four profile lines (32, 33, 34, and 35) in cell 5, which contains the Section 227 Beachsaver Reef, show general trends to finer sands after placement (Figure A14). The largest change was measured on lines 32 and 33, where the preinstallation samples were medium sand (possibly a spillover from the coarser beach fill sediment in the adjacent cell 4) and the postinstallation where the grain size was fine to very fine sands. The two more westerly profile lines in the cell (lines 34 and 35) had a similar distribution both before and after construction with only a slight fining from fine sand to very fine sand a year later.

The four profile lines in cell 6 (lines 36, 37, 38, and 39) represented the change in the high-tide area of the Section 227 Double-T sill (Figure A15). The preinstallation grain-size distribution on the western most profile in this cell, showed a medium sand distribution. After installation, the HT sample shifted to a fine sand distribution. A more poorly sorted, line 36, preinstallation HT sample

changed to better-sorted fine sand. There was little change in the size distribution of the middle profile lines (lines 37 and 38) HT sample over the study period.

A look at the sediment change at the HT area of the single profiles in cells 2 (line 23) and 3 (line 25) show the impact of the more established 1994 Beachsaver Reef grain-size changes (Figure A16). The most striking difference is the beach fill placed on the beach in December 2000 in cell 3. The fill material was only slightly reworked since it was placed and had the characteristics of a poorly sorted coarse to fine sand. Winter storms between 2002 and 2003 have reworked the fill material and it is now well-sorted very fine sand. The HT sample in cell 2 was the native sand of the area and was very fine sand. Little change was measured in the before and after grain-size distributions in this cell.

The three control cells 4, 7, and 8 have been grouped together to show the native sediment change at the HT location in the three cells without nearshore structures (Figure A17). Cell 4 (the eastern control cell) also received fill material in December 2000. This sand was relatively undisturbed medium sand in August 2003, but winter storms over the study period reworked this sand to a fine to very fine distribution by July 2003 as was observed in cell 3. Control cell 7 and cell 8 on the western side of the study area show little change in HT sediment distribution over the winter. Both of these cells reflect a slight coarsening of fine sand to medium sand over the winter months and also reflect the coarser sands on the western end of the study.

Midtide

The four profile line midtide samples grain-size distributions in cell 5 (Section 227 Beachsaver Reef) are shown in Figure A18. The preinstallation samples on the two lines closes to the adjacent groins (lines 32 and 35) showed a bimodal characteristic with a medium sand and very fine sand component. The two center profile lines (33 and 34) exhibited unimodal well-sorted very fine sand. After placement of the structure, the two samples adjacent to the groins became finer and fit into the very fine sand category. There was little change in the grain-size distribution of the center two lines and all lines were similar in distribution of grain sizes.

The midtide samples on all four profile lines of cell 6 behind the Double-T sill showed a coarse sand component in the preinstallation sampling (Figure A19). Each sample could be classed a poorly sorted with gravel, medium sand, and very fine sand components. After installation, the samples all became finer and better sorted except for line 36, which still retained a medium to fine sand component. All the rest of the samples were classed as very fine sand.

The midtide samples in cells 2 and 3 with the established 1994 Beachsaver Reef showed little change in grain-size distribution (Figure A20). The line 23 pre- and postinstallation samples showed little change while line 26 showed a switch from very fine sand to fine sand. All the samples were well sorted.

The midtide samples from the eastern control cell 4 showed the fine to very fine sand distribution of the sediment on the eastern side of Cape May Point. The

midtide samples from the western control cells 7 and 8 show the coarse, poorly sorted nature of the western end of the study area (Figure A21). There was little change in the cell 4 pre- and postinstallation samples. The midtide samples from cell 7 became slightly finer and better sorted but still fell in the medium to fine sand class. The poorly sorted preinstallation sands of cell 8 became a little better sorted postinstallation but still retained the coarse to medium sand class.

Nearshore

The nearshore samples are the best samples to directly assess the ability of the breakwater structures to influence sediment distributions since they are closest to the structures and inside any wave and current activity. The nearshore samples located inside cell 5 behind the Section 227 Beachsaver Reef all fell in the fine to very fine sand range (Figure A22). The preinstallation nearshore sample on line 32 near the east groin in the cell had the coarsest size distribution of this group. This sample became finer after placement. The rest of the samples retained a very fine well sorted sand classification from pre- to postinstallation. All the postinstallation samples became slightly finer than before the placement indicating that the breakwater may be trapping more very fine grained sand in the nearshore part of the cell profile.

The nearshore samples in cell 6 shoreward of the Double-T sill showed little change after placement (Figure A23). All of the samples fell in the very fine well sorted sand classification. There was a slight fining of the nearshore sand on the two profiles adjacent to the groins (lines 36 and 39) while there was a slight coarsening of sand on the two inner profiles. The basic size distribution remained very similar from before to after construction. The fact that the sill settled into the bottom may have had little effect on the sediment deposition in this area.

As with the Section 227 Beachsaver Reef in cell 5 the existing Reef in cells 2 and 3 show that there was a fining in sand in the nearshore behind both of the 1994 Beachsaver Reefs (Figure A24). Again, the sands were moderately well sorted very fine sand, but the August 2002 samples in both cells contained a medium sand size fraction. As of July 2003, this medium sand fraction was not present, indicating that finer material was deposited on the land side of the existing Beachsavers.

Samples were collected from the nearshore in the three control cells 4, 7, and 8 in August 2002 (Figure A25). The nearshore samples were collected in July 2003 but were lost in the processing and are not available for analysis. The August 2002 nearshore samples show that the eastern control cell 4 and the western control cell 7 consisted of very fine well sorted sand. The control cell 8 shows the coarse nature of the western cells with poorly sorted gravel to medium/fine sand mix even in the nearshore on that profile.

In general, the predominant sediment on the beach and nearshore of Cape May Point is a fine to very fine well sorted sand. Some medium size sand and fine gravel is also present in some of the samples, particularly in the offshore and to the west starting in cell 6 and becoming prevalent in cells 7 and 8. There was little change in grain-size composition attributed to the breakwater structures.

The sand became finer from 2002 to 2003 for most of the samples except on the western side where the sediment was slightly coarser. A slight fining in sediment in the nearshore behind the three Beachsaver Reefs was measured, but there was no significant change in the grain-size distributions in general.

Core Logs

The core logs from the cores collected in 2000 and 2001 along the line of the then proposed breakwater alignment show a view of sediment changes with depth (Figure A26). The long core NAB-19, located on the western edge of the Double-T alignment shows a general thickness of medium to fine gray sand. There are two thin (0.31 m or 1.0 ft) layers of clay at around -9.1 m (-30 ft) mllw and at -12.8 m (-42 ft). Below the first clay layer the sand takes on a tan color but is still medium to fine grain size. NAB-18 in the middle of cell 6 shows some thin layers of clay and organics below -1.8 m (-6 ft) mllw, some of which is mixed with silt size material and fine gray sand. The other short cores did not penetrate below the medium to fine sand layer. There are some thin layers of organic rich sediment in some of the cores. This occurrence of thin clay layers may explain the rapid settlement of the Double-T sill units, which may have compressed the clay layers.

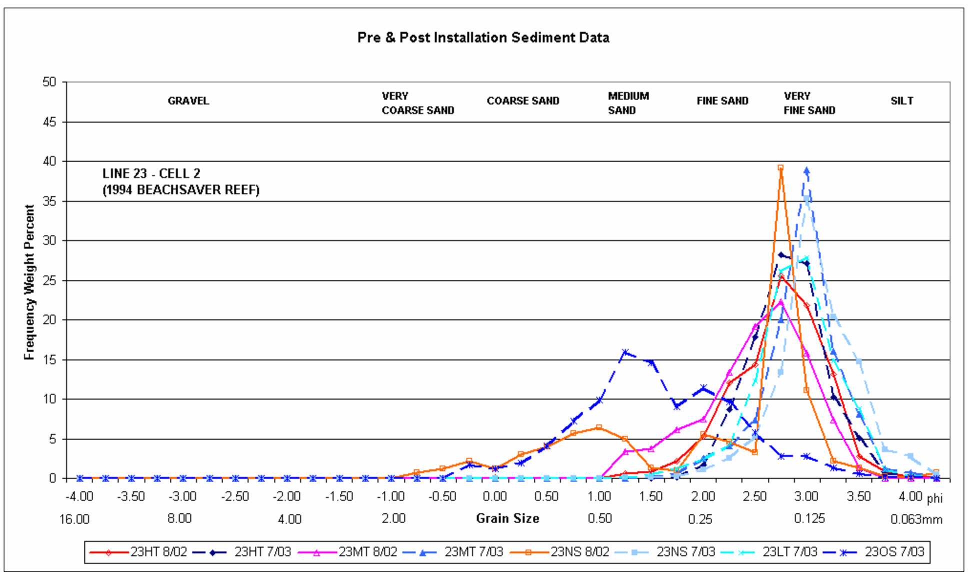


Figure A1. Sediment frequency plots of line 23 (cell 2). Solid lines are preinstallation samples (08/02), dashed lines are postinstallation samples (07/03). HT = high tide, MT = midtide, LT = low tide, NS = nearshore, OS = offshore

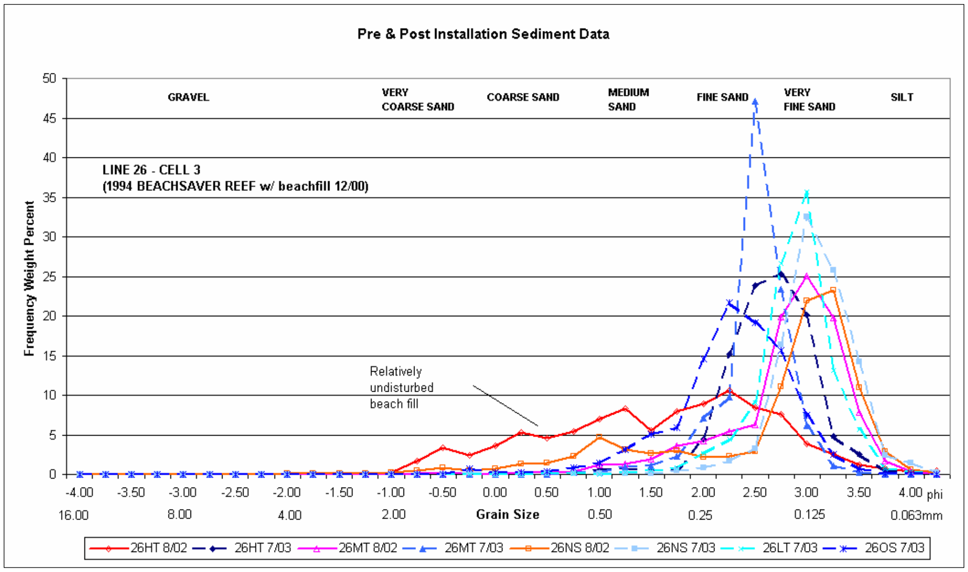


Figure A2. Sediment frequency plots of line 26 (cell 3)

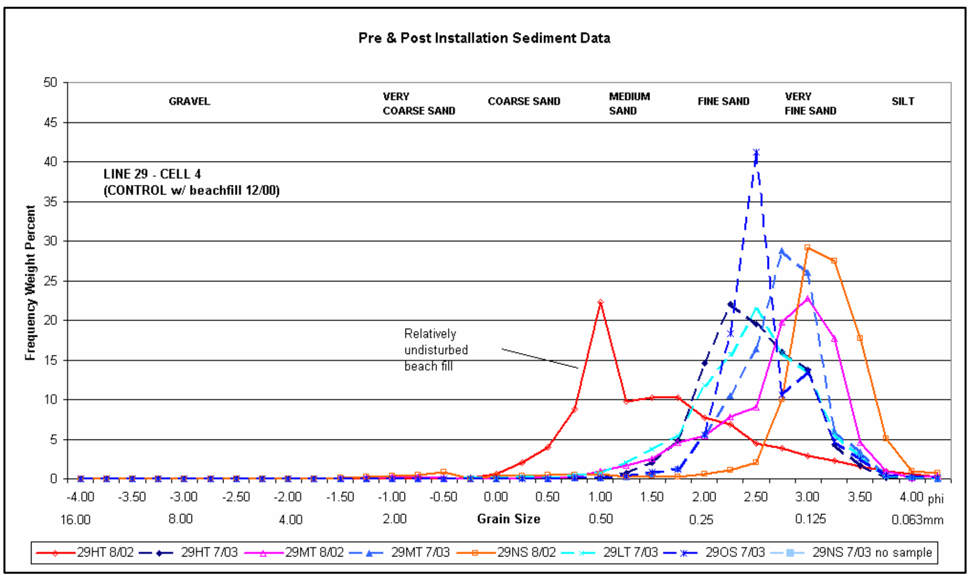


Figure A3. Sediment frequency plots of line 29 (cell 4)

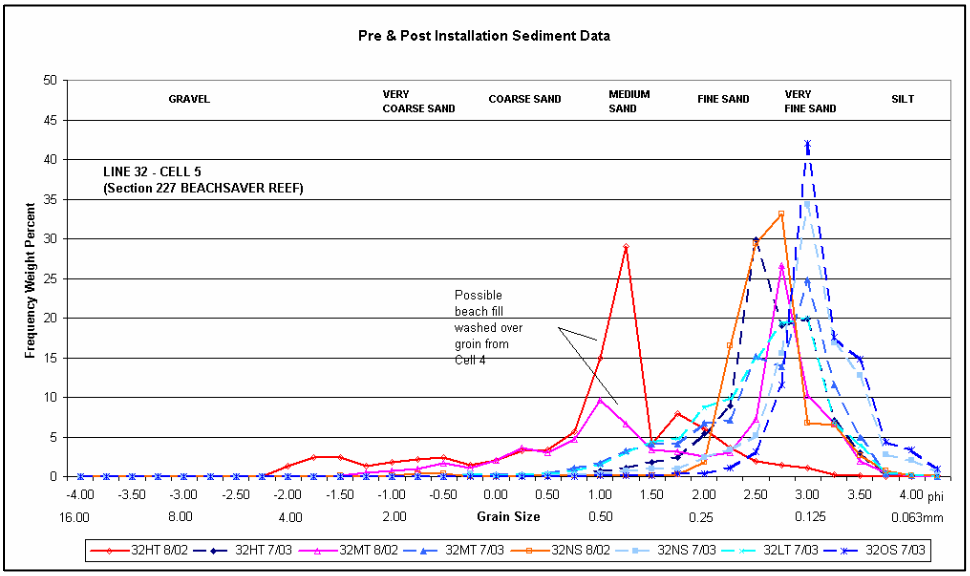


Figure A4. Sediment frequency plots of line 32 (cell 5)

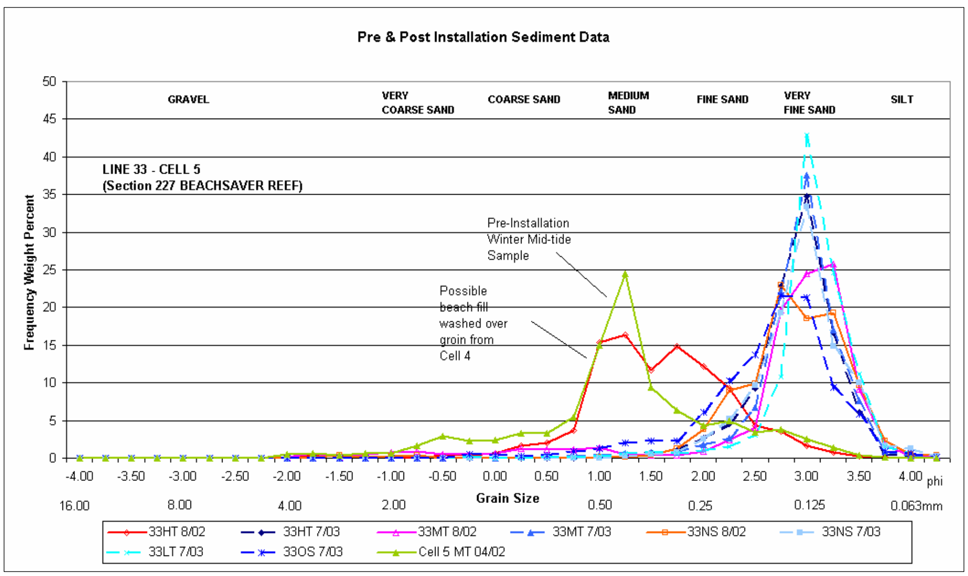


Figure A5. Sediment frequency plots of line 33 (cell 5)

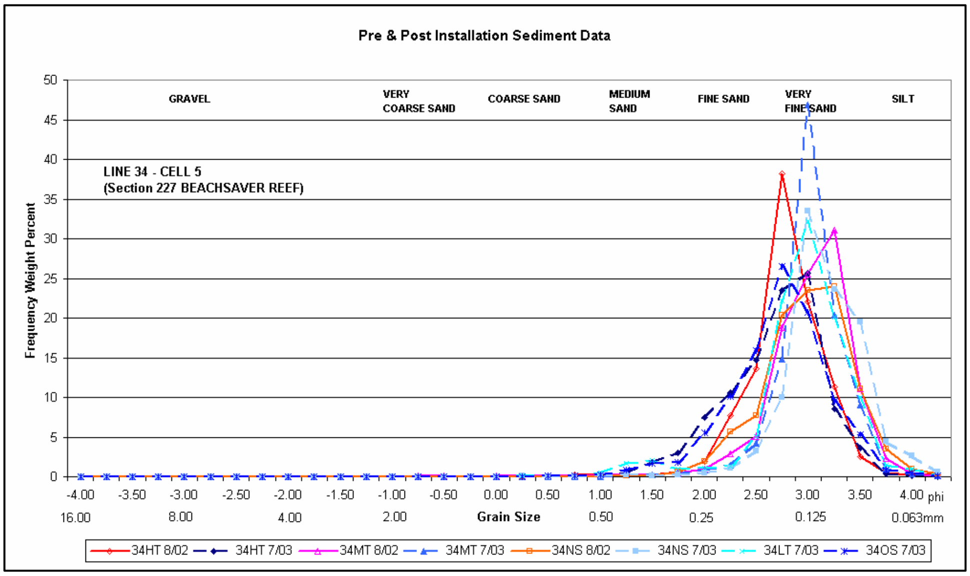


Figure A6. Sediment frequency plots of line 34 (cell 5)

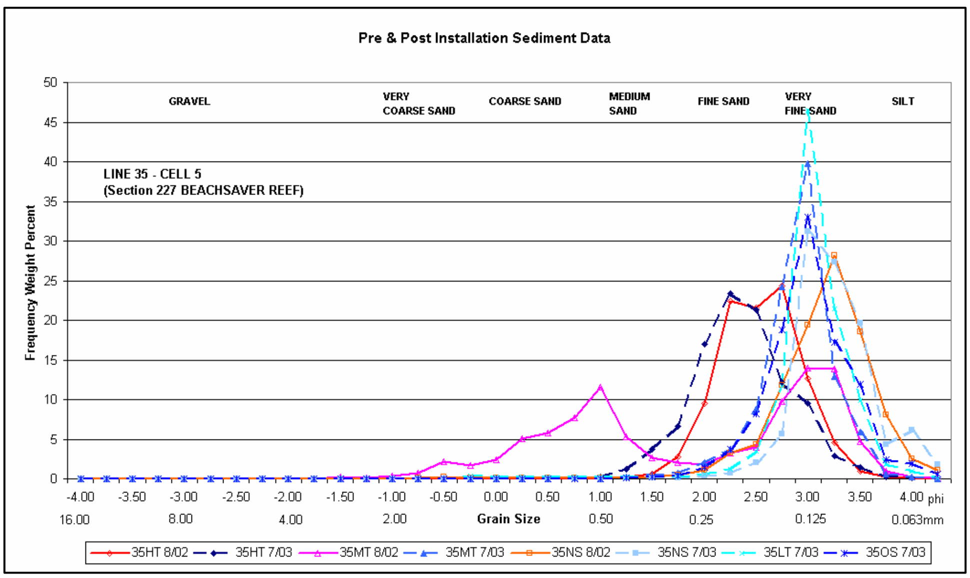


Figure A7. Sediment frequency plots of line 35 (cell 5)

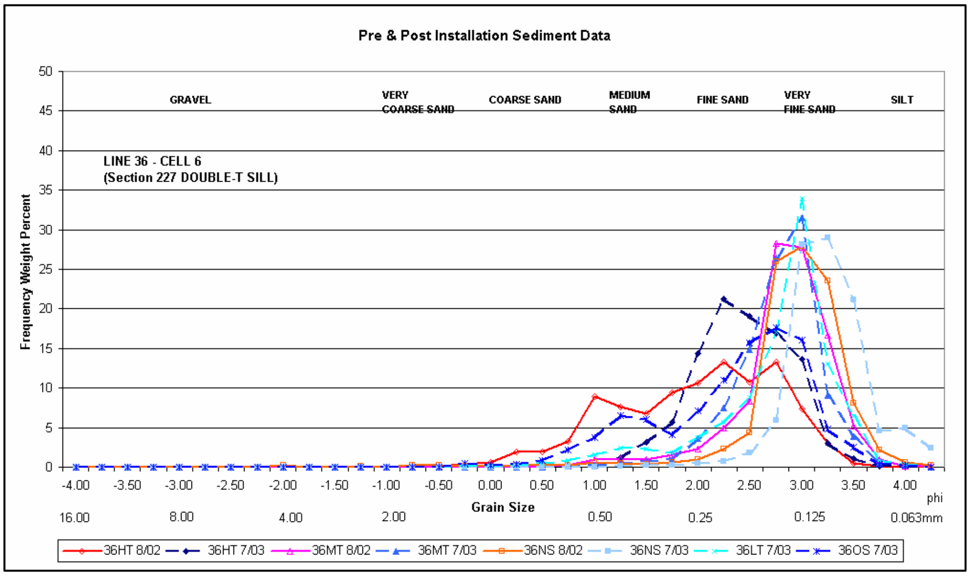


Figure A8. Sediment frequency plots of line 36 (cell 6)

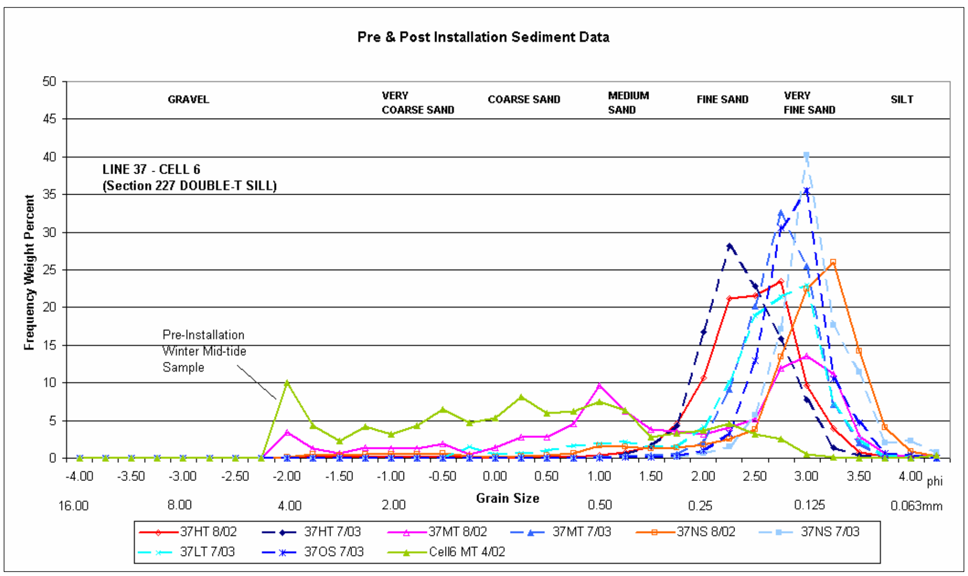


Figure A9. Sediment frequency plots of line 37 (cell 6)

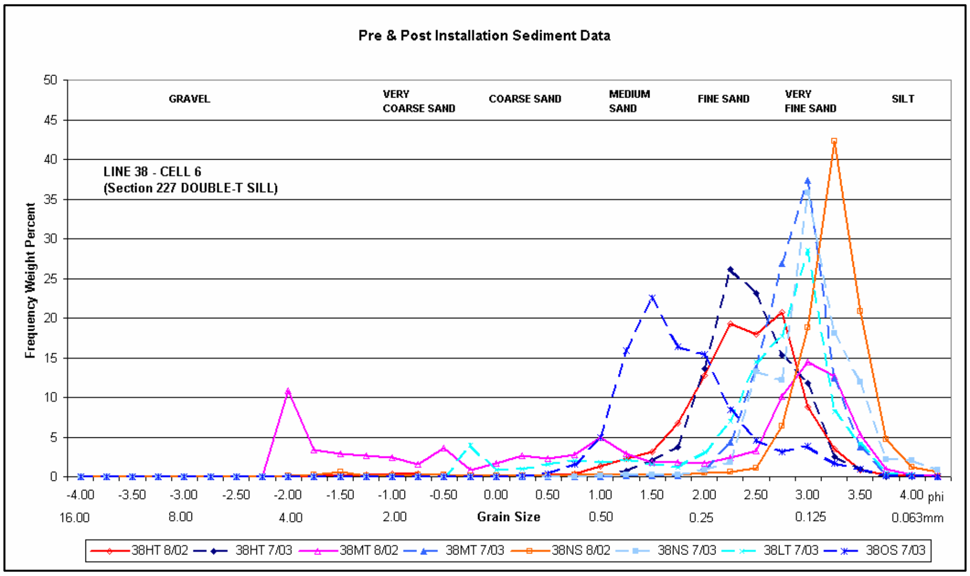


Figure A10. Sediment frequency plots of line 38 (cell 6)

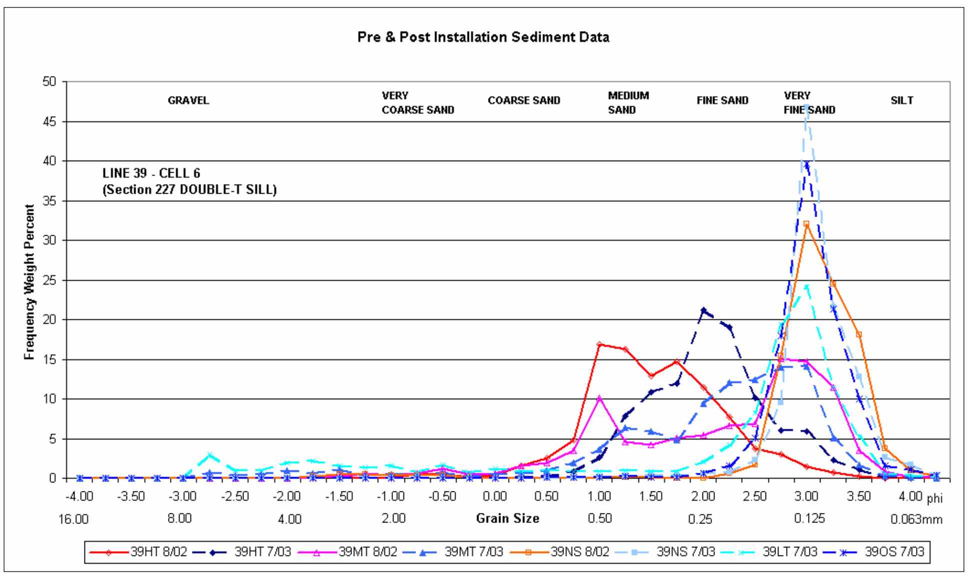


Figure A11. Sediment frequency plots of line 39 (cell 6)

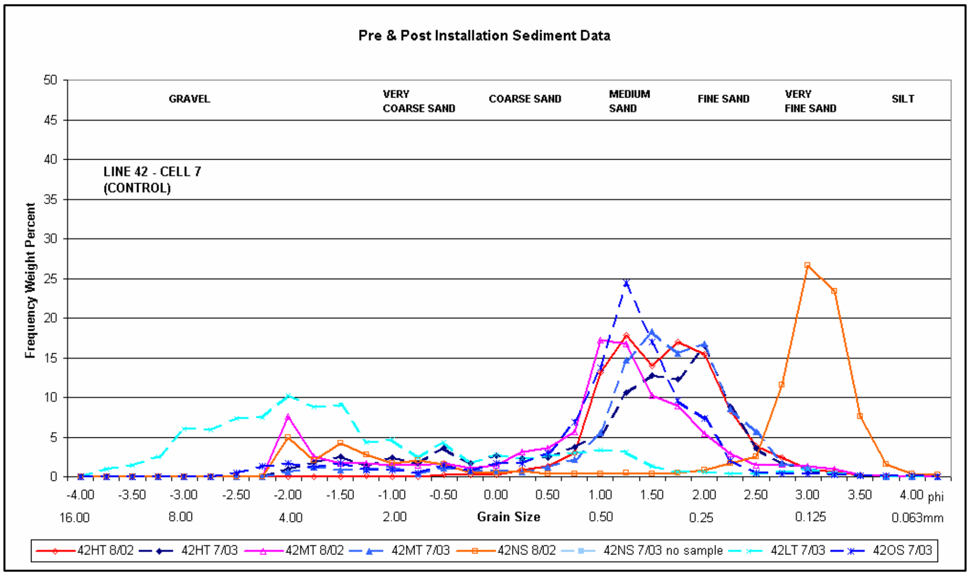


Figure A12. Sediment frequency plots of line 42 (cell 7)

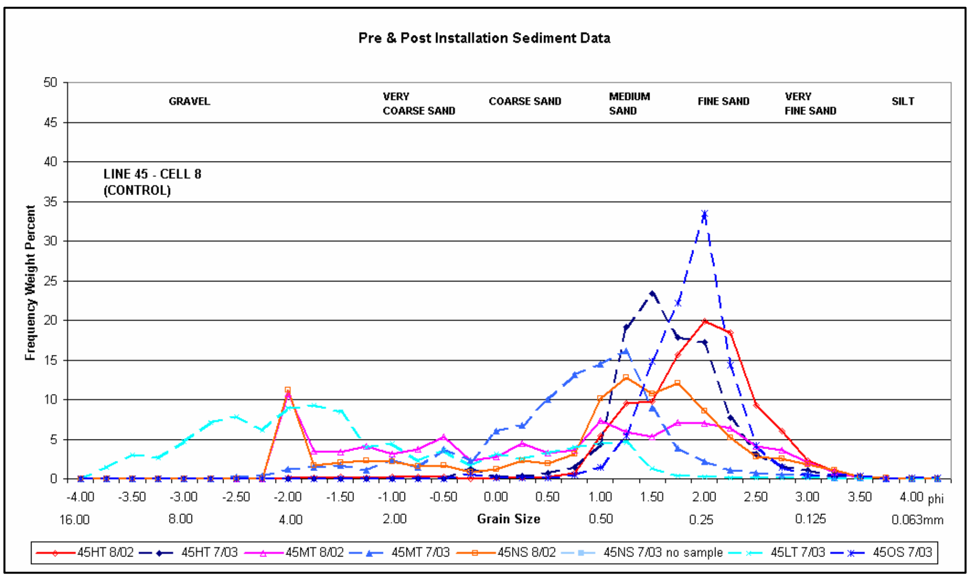


Figure A13. Sediment frequency plots of line 45 (cell 8)

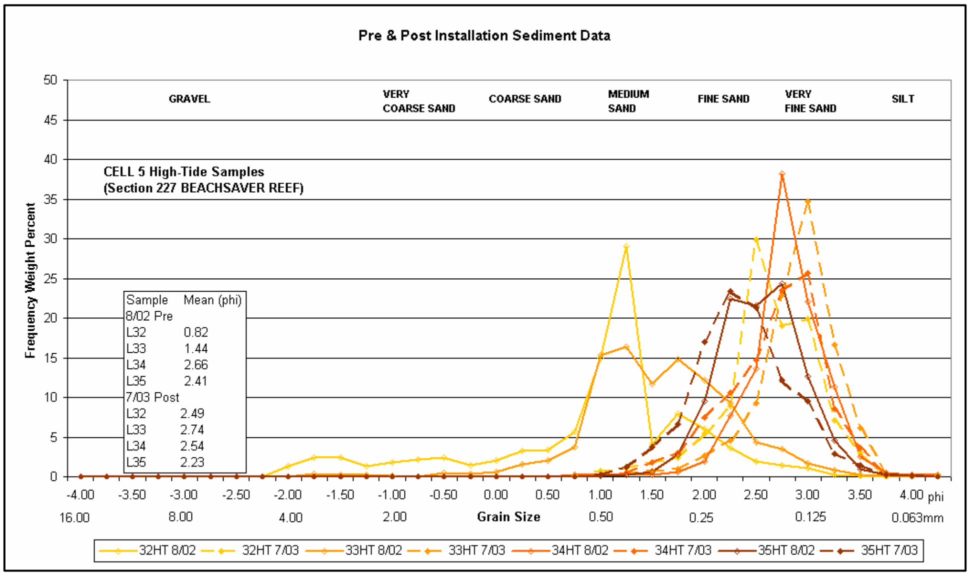


Figure A14. Sediment distribution change between 8/02 and 7/03 of high tide samples in cell 5

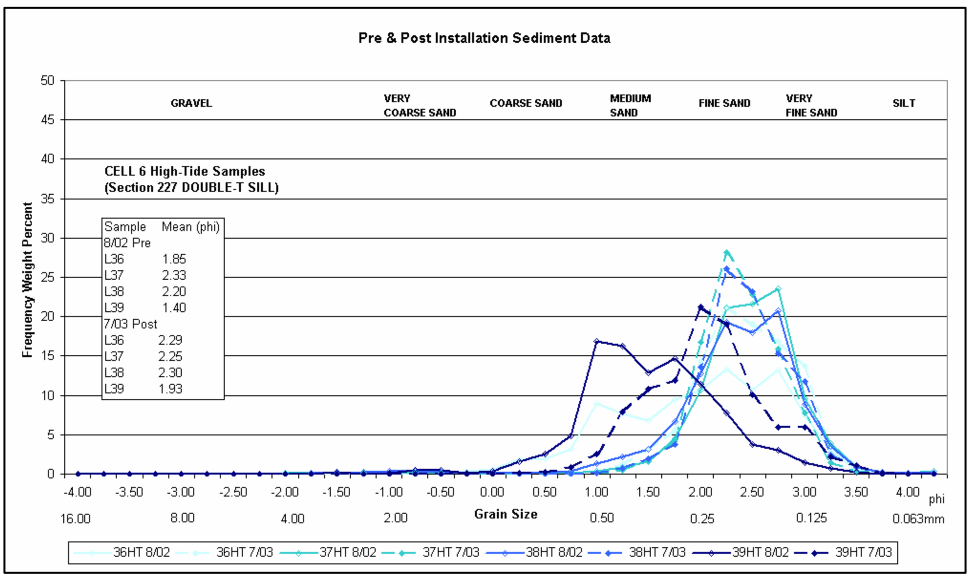


Figure A15. Sediment distribution change between 8/02 and 7/03 of high tide samples in cell 6

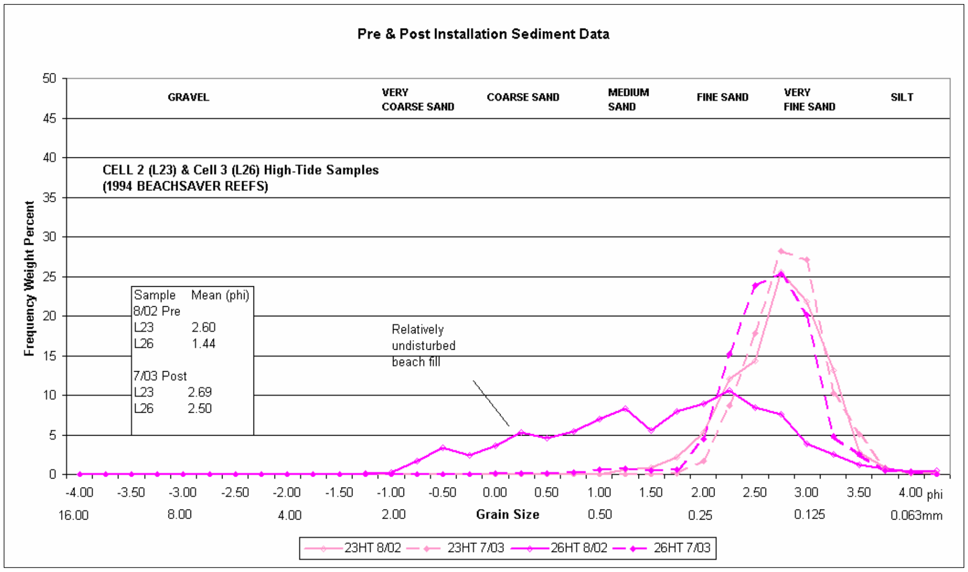


Figure A16. Sediment distribution change between 8/02 and 7/03 of high tide samples in cells 2 and 3

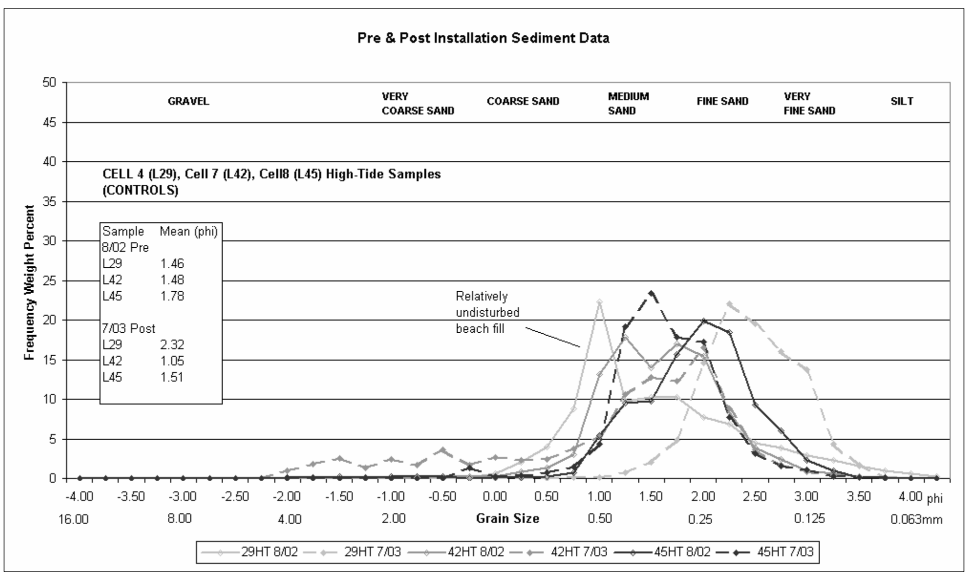


Figure A17. Sediment distribution change between 8/02 and 7/03 of high tide samples in cells 4, 7, and 8

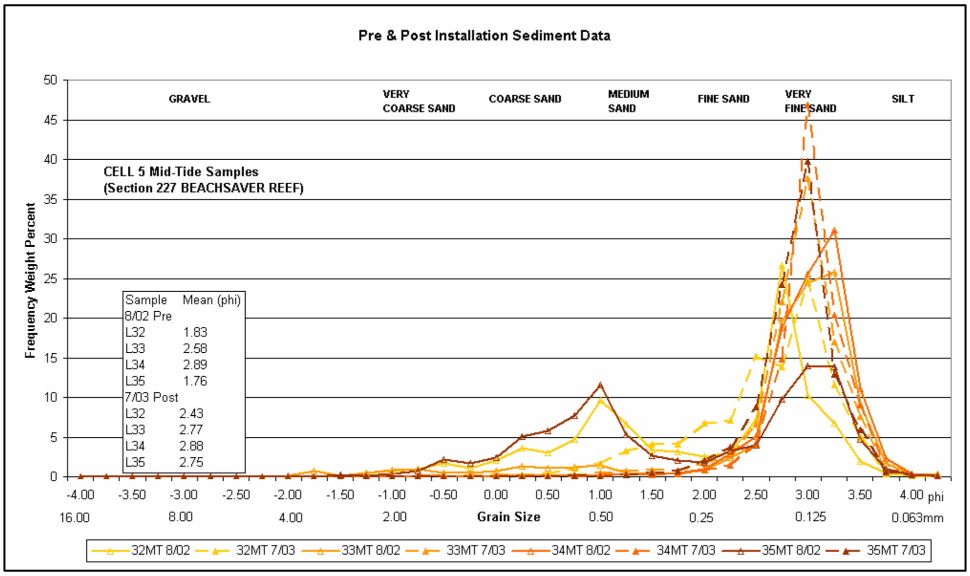


Figure A18. Sediment distribution change between 8/02 and 7/03 of midtide samples in cell 5

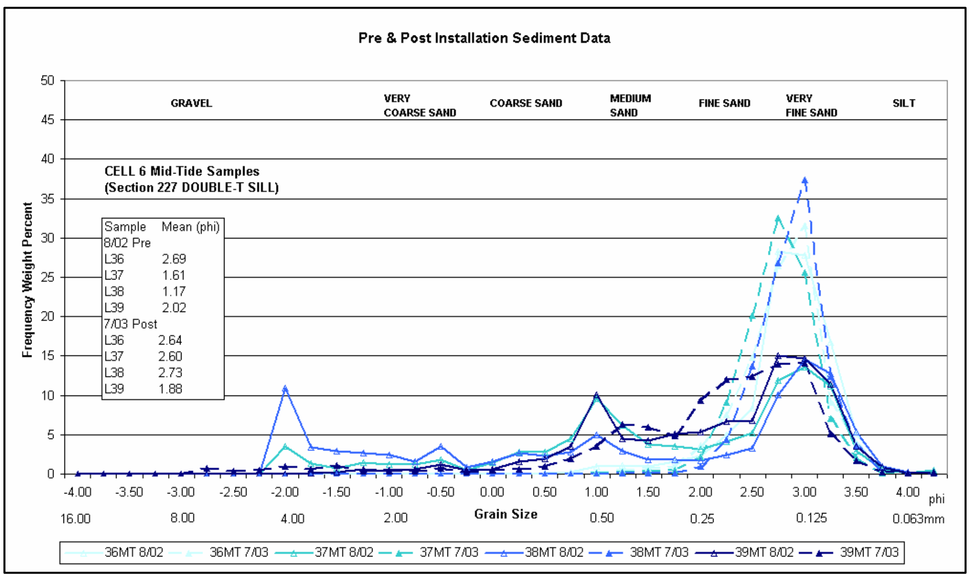


Figure A19. Sediment distribution change between 8/02 and 7/03 of midtide samples in cell 6

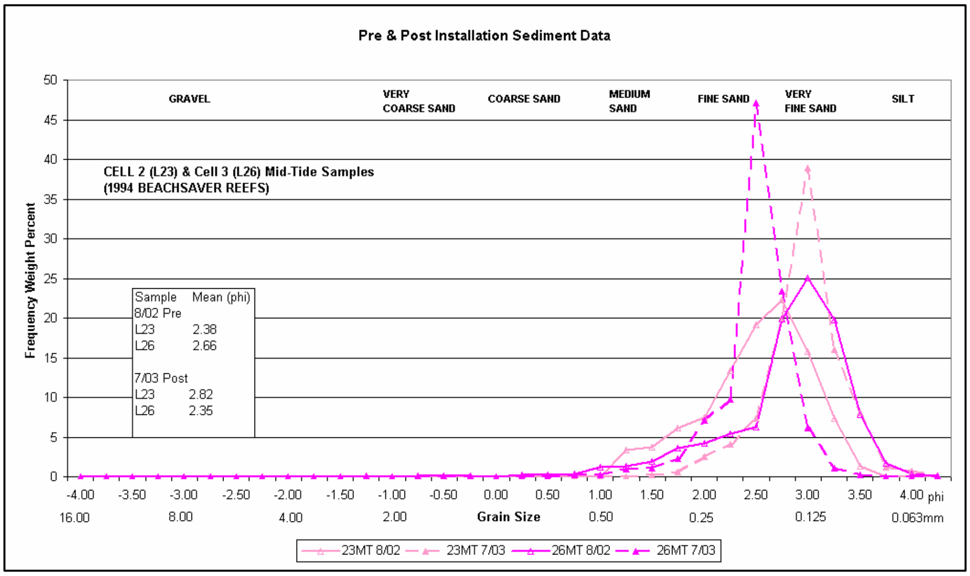


Figure A20. Sediment distribution change between 8/02 and 7/03 of midtide samples in cells 2 and 3

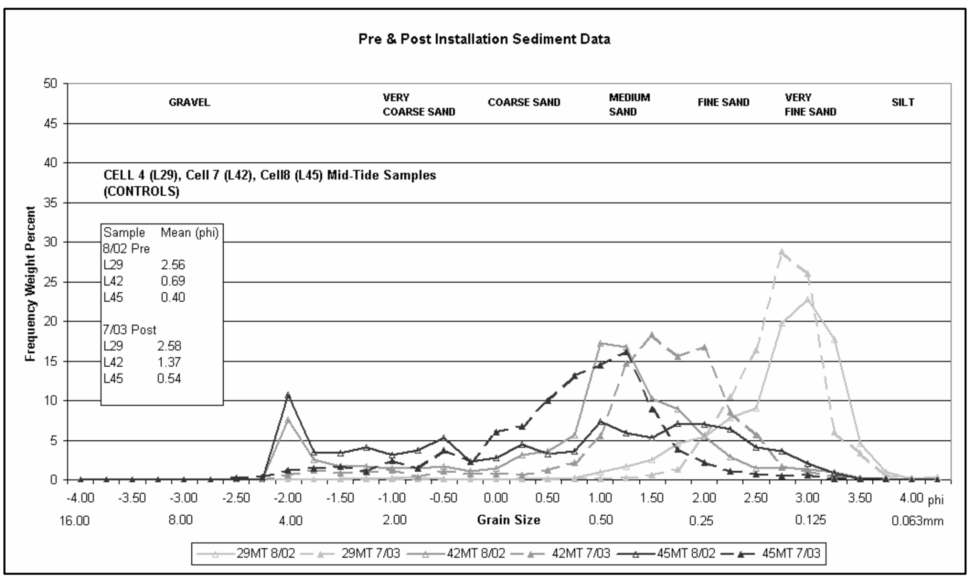


Figure A21. Sediment distribution change between 8/02 and 7/03 of midtide samples in cells 4, 7, and 8

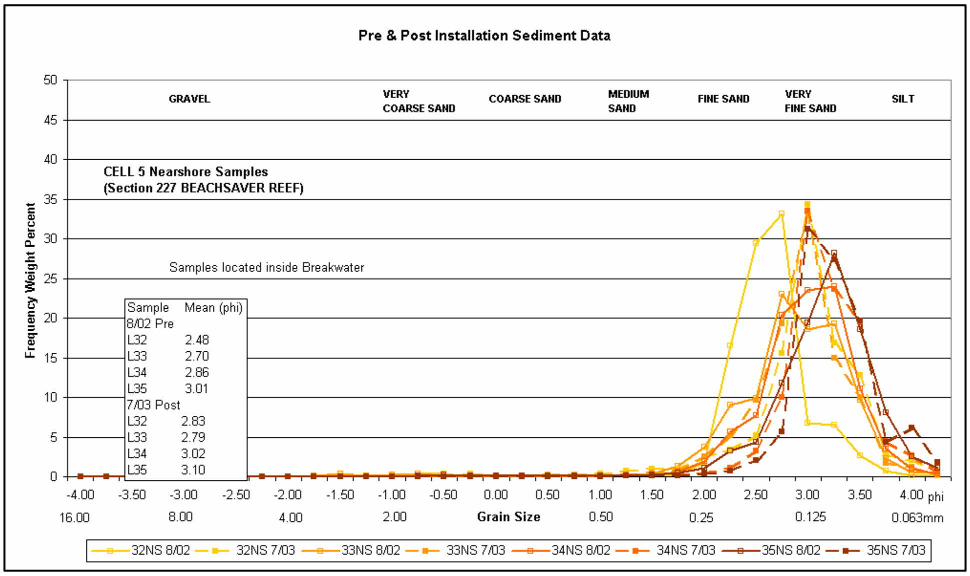


Figure A22. Sediment distribution change between 8/02 and 7/03 of nearshore samples in cell 5

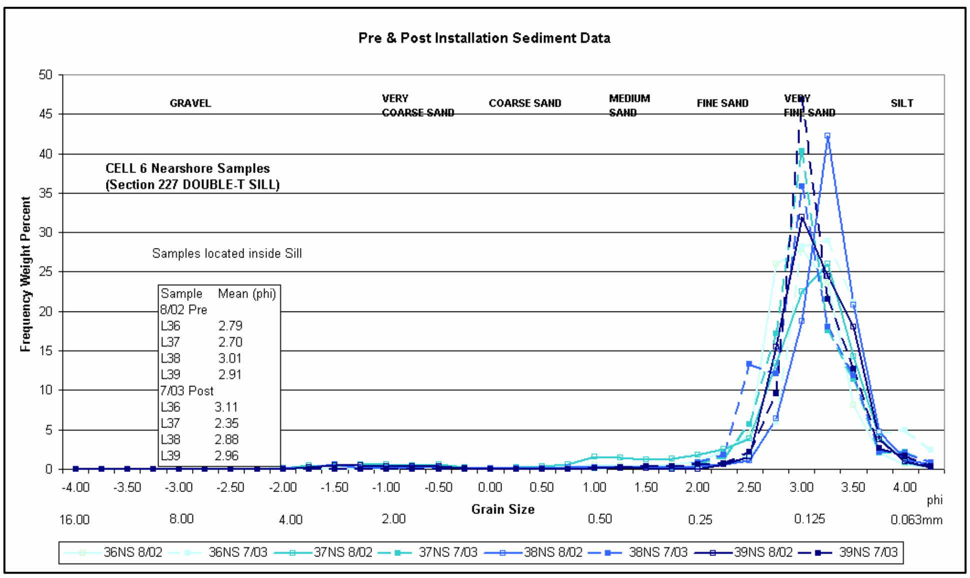


Figure A23. Sediment distribution change between 8/02 and 7/03 of nearshore samples in cell 6

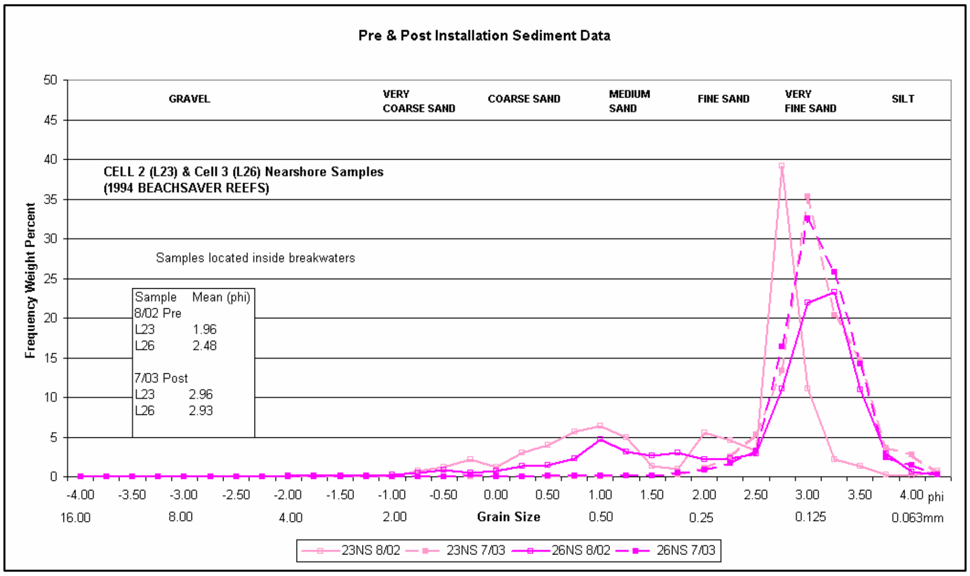


Figure A24. Sediment distribution change between 8/02 and 7/03 of nearshore samples in cells 2 and 3

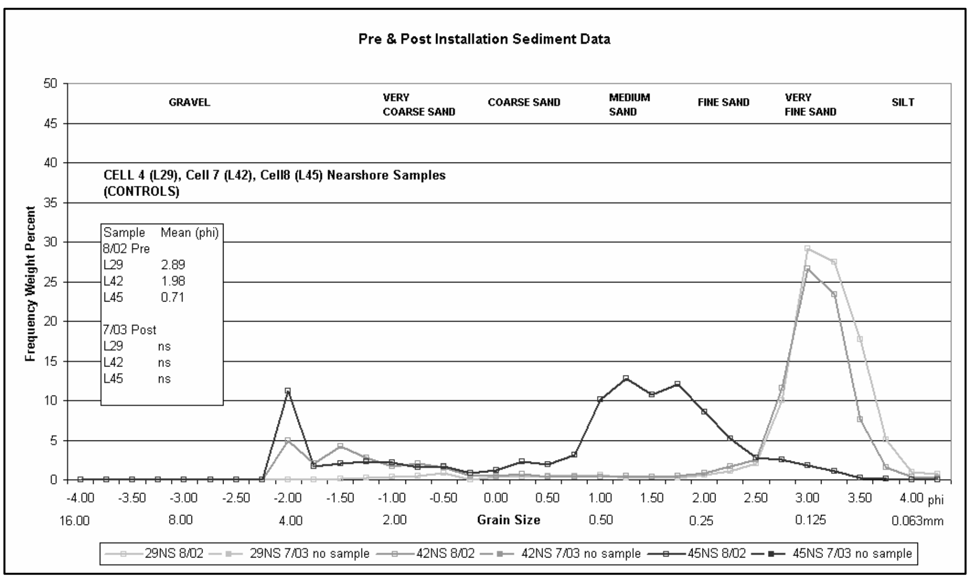


Figure A25. Sediment distribution change between 8/02 and 7/03 of nearshore samples in cells 4, 7, and 8

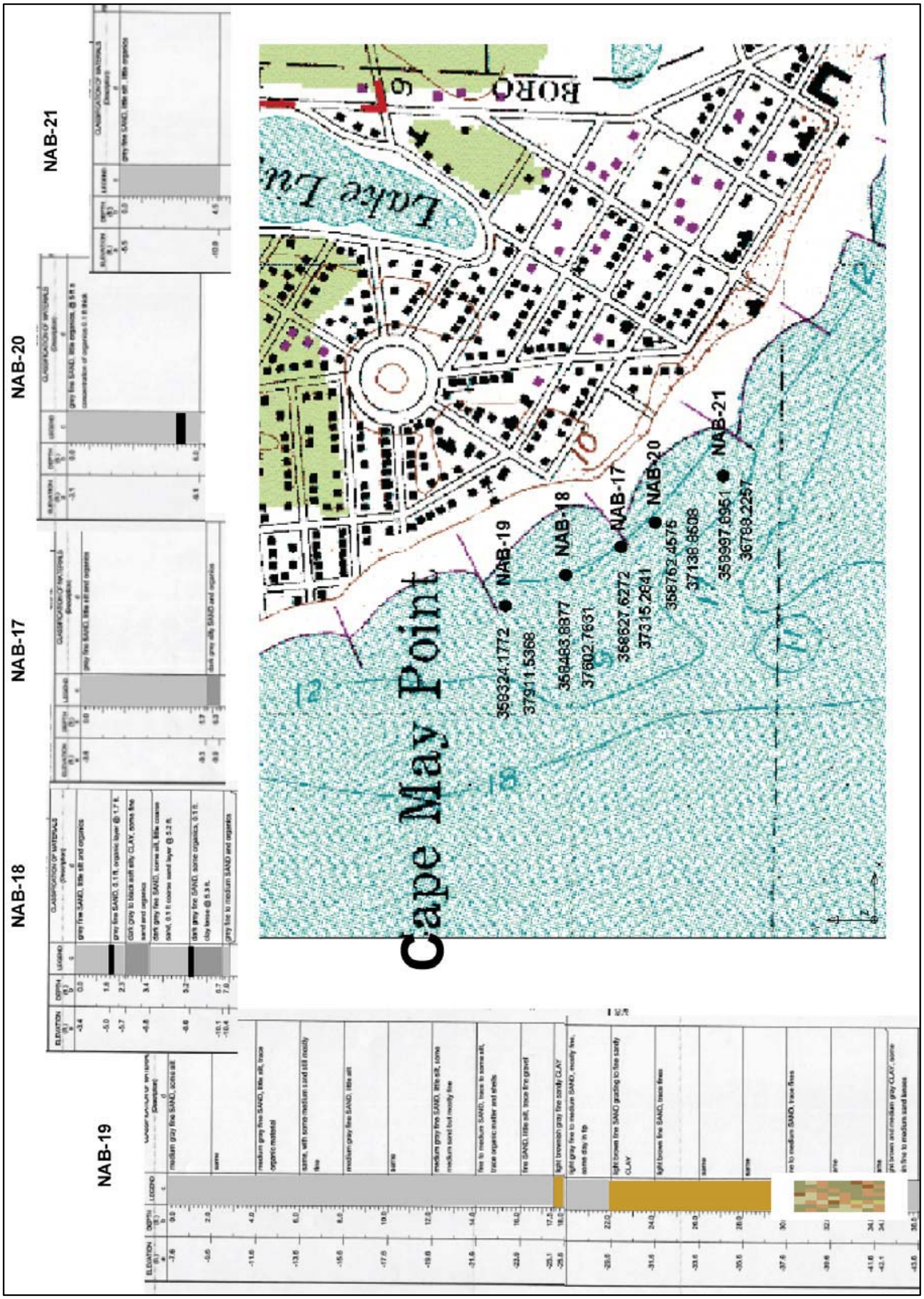


Figure A26. Core logs of preinstallation sediment cores

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14. ABSTRACT
The first National Shoreline Erosion Control Development and Demonstration project is located at Cape May Point, NJ, the southernmost beach along the New Jersey coast. This site was selected to evaluate the functional, structural, and economic performance of the patented Beachsaver Reef prefabricated concrete submerged breakwater and the less expensive prefabricated concrete structure called a Double-T sill. This demonstration project was developed through a cooperative effort of the U.S. Army Corps of Engineers Headquarters, Coastal Engineering Research Board, Coastal and Hydraulics Laboratory, Philadelphia District, the state of New Jersey and Cape May Point. Cape May Point has a history of beach erosion due to the combined influence of waves and tidal currents due to its location at the north side of the entrance to Delaware Bay. The Beachsaver Reef was installed between August and September 2002 at the seaward end of groin cell 5. The Double-T sill was installed in September 2002 at the seaward end of groin cell 6. Groin cell 4 acted as a control cell without any structures, but a small beach fill was placed twice during the monitoring period. Monitoring includes dune, beach and nearshore beach profile surveys, structure surveys to measure settlement and scour, waves and current measurements, sediment sampling and aerial photography analysis of shoreline change. After one year, evaluation of profiles and shoreline change indicates the functional performance of the Beachsaver Reef has stabilized the shoreline and retained sand within the cell, while the Double-T sill has not. The structural performance indicates that the Beachsaver Reef has experienced settling in the western part of the cell while the Double-T has settled below the surface within the first 6 months. The economic analysis will be evaluated after the third year of monitoring.

15. SUBJECT TERMS

Beachsaver reef	Double-T reef	Prefabricated concrete submerged breakwaters
Cape May Point, NJ	National Shoreline Erosion Control Development and Demonstration Program	Project performance monitoring
		Section 227 demonstration site

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